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Feasibility of ceramic products as trickling filter media

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FEASIBILITY OF CERAMIC PRODUCTS AS TRICKLING FILTER MEDIA

BY

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I. INTRODUCTION

A. The Nature of Trickling Filters.

Trickling filters, sometimes known as sprinkling or percolating filters, are artificial beds of coarse, prepared material over which sewage is applied for purification. The beds vary in depth from five to twelve feet. The filter material, or filter medium, may be coarsely crushed granite, dolomite, slag or other substance. The sewage is applied to the upper surface of the bed by moving or stationary distributing devices. Common stationary distributing devices include spray nozzles and splash plates. Moving types of distributing devices include the revolving arm, traveling "length-of-bed", and tipping tray types. Various combinations of auxiliary devices may be used with these distributors. In practice, trickling filters are commonly preceded by some preliminary treatment such as screening or sedimentation which removes a large portion of the readily settlable solids from the sewage.

As the sewage trickles through the bed a biological or microbial film, forming a jelly-like mass, develops on the surface of the filter medium. The essential changes which result in the purification of the waste are brought about by the biological agents contained in this film. The filter, when operating normally, converts the foul smelling, cloudy sewage into a transparent, stable liquid, containing flocculent suspended particles and having a slightly earthy odor. The size of the medium in the filter is such as to exert little or no filtering or straining action on even the largest particles contained in the sewage. Perhaps a trickling filter should properly be called a biological contact bed.

The use of trickling filters for sewage purification is widespread. Forty-seven Iowa towns and cities use trickling filters for sewage purification. Trickling filters are quite free from extreme fluctuations in operation and require a minimum of attention for their successful operation. Furthermore, no expensive auxiliary equipment is required, nor is the power requirement for the plant operation excessive.

The purpose of this investigation is twofold:

First, to obtain additional information concerning biochemical mechanism of operation of a trickling filter. Many of the limiting factors, optimum conditions, operating characteristics and capacities obtaining in a trickling filter have not been determined.

Second, to determine the feasibility of utilizing ceramic products as trickling filter media. In practice, crushed rock, slag, or other easily obtainable inert materials are commonly used as filter media. These materials, even though carefully selected and sized, are not as uniform in either size or shape as may be desired. Furthermore, ceramic shapes appear to have more of the desirable characteristics of an ideal medium than the materials in common use. The use of ceramic filter media would enlarge the Iowa ceramic industry's market.

II. HISTORICAL

A. Introduction

The development of the trickling filter as commonly used today is a progressive development from the land irrigation method of sewage treatment, through the intermittent sand filter, and finally to the present trickling filter. This development is discussed in some detail by Buswell (7) Fullerand McClintock (12) and Metcalf and Eddy (26) and will for this reason not be discussed here.

B. A Brief Historical Review of Research on Trickling Filters.

The earliest research work on the operation of trickling filters was conducted at the Lawrence Experiment Station (10). In fact, the trickling filter as such was developed there. The work on sewage purification was instituted in 1886 and has continued to date. Trickling or sprinkling filters are an outgrowth of studies on the bacterial purification of sewage made at the station during the first three years of its operation. In the early Lawrence experiments after the first principles of successful intermittent sand filtration had been well worked out, various filters of coarse materials were constructed. The changes brought about in sewage, when passed through these filters, were carefully noted and recorded in the special report of 1890 and in the many subsequent reports.

In 1889, a filter of "gravel-stones" was put into operation at the station, the stones used being of such size that they would pass through a screen having a mesh three-eights of an inch square but not through a screen having a mesh one-eighth of an inch square. At the same time another filter was constructed of coarse gravel, the size being such that none were less than three-fourths of an inch in diameter nor more than one and one-fourth inches. Good nitrification occurred in these filters, 99 per cent of the bacteria in the sewage applied were removed and the report in summarizing the results says, "the purification of sewage by nitrification and the removal of bacteria is not to any essential degree a mechanical but a chemical change". Further, "the experiment with gravel stones gives us the best illustration of the essential character of intermittent filtration of sewage, the slow movement of liquid in films over the surface of stone with the air in contact." These filters were operated at rates as high as 200,000 gallons per acre per day, the sewage being applied in sixty or seventy doses a day.

In 1892 (10) two gravel-stone filters were put into operation in such a way that air was drawn through them. These filters were successfully operated at rates up to 500,000 gallons per acre per day. In 1895 two filters were put into operation using a forced draft aeration. One of the filters contained gravel stones and the other cinders. These filters were operated for considerable length of time at 712,500 gallons per acre per day and for shorter periods up to one million gallons per acre per day. Unusually high nitrification was obtained in these filters even though not all the ammonia was oxidized.

Although it was felt at this time that artificial aeration was desirable for trickling filters, further studies were made starting in 1897 to construct filters without artificial aeration. At this time two filters containing larger crushed rock, eighteen feet in depth were put into operation. Rates of application up to 2 M.G.A.D., and for short periods, up to 3 M.G.A.D. were used. "Highly nitrified, stable effluents containing free oxygen" were obtained. It was found that the extreme depth of beds was not necessary, and they were reduced to ten feet.

The marked effect of temperature upon the purification obtained, was early recognized. The purification obtained during winter operation was markedly less than that obtained during the summer months. Some difficulty was experienced during operation because of the freezing of the dosing device.

In all of these experiments a domestic sewage from the city of Lawrence, Mass. was used. In this early work the analyses used as a criterion of purification were principally the nitrogen determinations, oxygen consumed determinations and bacterial counts. Occasionally the dissolved oxygen content and relative stability of the effluents are reported. Unfortunately the oxygen demand determination had not come into use at that time.

Recently workers in the field have come to rely more and more on the oxygen demand determination as a criterion of purification.

The question of the proper method of distributing sewage upon the filters, and the effect of unequal distribution upon the quality of the filter effluents, has received attention from the beginning. It was determined early that the best results were obtained when the sewage was distributed most uniformly over the surface. Many different types of distributing devices were used both on small experimental and large practical scale filters. One of the earliest experimental distributers is described (10) "consisting of four flat arms forming a cross, suspended horizontally at the middle, with edges projecting from half an inch to a sixteenth of an inch above the upper surface. Sewage is applied at the middle and flows out on the four arms, overflowing the edges and running out at the ends, a foot from the side of the tank. By revolving the cross 90 degrees and back while the sewage is running on, it becomes evenly distributed over the surface." This distributer was put into operation in 1888.

Almost every imaginable type of distributer has since been used: revolving types, as above, with jets on the arms under pressure, revolving sprays such as are used for lawn spraying with cones or splash plates above or below, fixed nozzles, fixed nozzles with rotating cones above and below, tipping troughs with splash plates, a thin layer of fine sand on the upper surface, perforated trays, etc. have been used with varying success.

In all the early work, the tendency was to follow the practice of intermittent sand filter operation and apply the sewage at certain time intervals. In the case of intermittent sand filters this time interval or dosing cycle is of appreciable length, often 30 minutes to four or more hours. It was early recognized that the dosing cycle for trickling filters should be shorter than that for intermittent sand filters, but dosing cycles of 20 to 30 minutes were quite common. It was not until comparatively recently (24) that it became evident that short dosing cycles, as short as 3 minutes were advantageous. In fact, there is at present a tendency to go to a continuous dosing device, such as the revolving arm type of dosing device.

It should be pointed out that if nozzles are designed for continuous dosage, the openings will be smaller than for intermittent dosage assuming the same rate of application and as a consequence they will be more subject to clogging. With the low rates of application common in the earlier filters this is especially important, and almost made intermittent dosage imperative. With the high rates of dosage in use today, or contemplated for the future, this factor becomes less important.

In 1913 some studies were instituted (11) to determine the effect of filter depth on the efficiency and capacity of the filter. Four filters 4, 6, 8, and 10 feet deep were put into operation. The rock filter medium was three-fourths to one and one-half inches in size. The rate of application was adjusted, after the filters had built up, to such a point as to obtain effluents of equal quality. The nitrification and relative stability obtained were used as the principal criteria of quality. In these experiments the following rates of application gave equal purification:

Depth (feet)	Rate of application M.G.A.D.	Gallons per acre per day per foot of depth
4	0.5327	116,600
6	0.5851	134,250
8	1.801	220,906
10	3.733	350,100

These results seem to indicate that under the conditions noted, the capacity of a 10 foot filter is nearly 12 times as great as that of a 4 foot filter, and furthermore that the capacity of the filter per foot of depth is three times as great for the 10 foot filter as for the 4 foot one. The dosing cycle is not stated but it is assumed to be quite long, perhaps 20 to 30 minutes. Some studies of the time of flow through the filter were made at these various rates of application, using the time of flow of an added salt concentration as a criterion. It was found that the time of flow of the salt solution through the filters was nearly the same when the rates of application were such as to give equal purification. Under the conditions of the experiment 50 per cent of the salt flowed through the filters in about 50 minutes.

When this work was repeated using one to two and one-half inch rock for filter medium the rates of application per foot of depth for the same degree of purification were in about the same order as before.

This work was again repeated in 1933, (31) using the filters having three-fourths inch to one and one-half inch filter medium and a somewhat shorter dosing cycle. The rates of application for effluents of about equal quality were 178,-000, 219,000, 319,000, and 375,000 gallons per acre per day, per foot of depth, for the 4, 6, 8, and 10 foot depths. The capacity of the 10 foot filter in this case is about twice as great per foot of depth as of the 4 foot filter.

It is entirely possible that the difference in capacity of the filter per foot of depth in these experiments is caused by the difference in the manner in which the flow occurs in filters of various depths. When a large dose is applied periodically to the filter, a surge of flow occurs throughout the filter, but the surge is smoothed out as it flows down through the filter. In a deep filter such as a 10 foot one, the surge is almost completely smoothed out at the bottom, while in a 4 foot filter this is not the case. If the sewage is applied continuously to the surface of the filter, giving similar flow conditions in the filter regardless of depth, it is possible that the capacity of the filter per foot of depth would not be nearly as dependent upon the total filter depth as these experiments indicate. Also, it is possible that had B.O.D. determinations of the effluents been used as a criterion of purification, the inferences would have been somewhat different.

The necessity of free oxygen in the atmosphere of a trickling filter has been assumed from the first. The earliest filters were artificially aerated. However, very little work has been done to show the benefits of aeration, and even today there is some question as to the amount of aeration necessary. The earliest work on the effect of small amounts of free oxygen upon the nitrification was carried on in 1889 at the Lawrence experiment station (27). A filter having an air-tight case was set up so as to permit a recirculation of the atmosphere by means of a water aspirator. The filter was operated, and the atmosphere of the filter recirculated until no oxygen remained. It was found that when no oxygen remained, nitrification ceased. By carefully regulating the amount of fresh air admitted it was found that "a small amount of oxygen (1 to 3 per cent) in the air of the filter is as effective, or very nearly so, as a larger quantity, provided the air is changed (recirculated) so often that some of the oxygen is always present at every point."

Bach (3), Blunk (5) and Gaultier (19) present evidence that oxygen is necessary for purification in a trickling filter. However, their evidence is based largely upon calculations, which are in turn based upon speculations or assumptions. Very little experimental data are presented. Bach suggests that very low concentrations of carbon dioxide are inhibitory to purification (probably B.O.D. removal). Levine and Goresline (25) confirm the early work showing that ventilation is necessary for purification. In their work two 6 foot filters filled with carefully washed clinkers, five-eights to two inches in size were dosed at the rate of about 800,000 gallons per acre per day with a 2 per cent milk waste. When the bottoms of the filters were closed, so as to prevent bottom ventilation, nitrification ceased, the B.O.D. reduction became very low and the filters tended to clog. When the bottoms of the filters were opened the filters again operated normally, though they had to be washed for a proper recovery. Unfortunately no analyses were made of the atmosphere within the filters. Levine (24) carried on some experiments with artificially aerated filters. "Packing house waste which had been settled for about one and one-half hours was applied to a filter three and one-half feet square and ten feet deep at a rate of 7 M.G.A.D. for a period of six months. The filter was constantly aerated through a perforated grid at itsbottom. The purification effected was very satisfactory (about 40 per cent B.O.D. reduction) considering the high rate of application, and there was no evidence of serious clogging." The B.O.D. of the applied waste was about 1000p.p.m.

The rate of runoff from the filters was shown early (11) to depend upon the nature of the filter medium and upon the nature of the film. The exact mechanism of flow through a filter has not been determined, though several workers speculate on the subject. Blunk (5) says "purification occurs not by flowing over the biological film but by exchanging with and forcing out part of the firmly held liquid in the film", thus assuming that at least part of the flow is through the film. This idea is in part substantiated by Levine (24) who demonstrates that the purification obtained in the effluent at the time of maximum runoff is not nearly as great as that obtained at the time of minimum runoff. He further gives evidence that greater purification is obtained when the runoff rate is more uniform. That is, unless other factors become operative, the greatest purification is obtained when the filter is dosed continuously at exactly the rate at which the sewage can flow through the microbial film.

Trickling filters are adaptable to the treatment of any waste that will support biological growth. That is, with certain limitations, trickling filters have treated practically every type of waste containing sufficient organic material to support biological activity and which do not contain toxic materials. In general the waste should not contain appreciable quantities of settlable solids, nor should the temperature be much below 45 degrees Fahrenheit. Settlable solids are more readily removed from the waste by sedimentation than in a trickling filter, and furthermore the settlable solids, if present in excess, will clog the filter. The action of the trickling filter is dependent upon biological growth and since biological activity does not continue very actively below 45 degrees Fahrenheit, the action of a filter at that temperature will not be very pronounced.

C. The Flora and Fauna of Trickling Filters.

An attempt was made early to identify some of the organisms found in trickling filters (27). At this time it was felt that the organisms responsible for the changes brought about in the filter were largely bacteria, especially the nitrifying organisms. This view seems to have been held as late as 1908 (10). This view may be partly justified when it is realized that particular interest was being directed toward the removal of bacteria in a filter rather than toward a study of the function of the bacteria in the purification.

In 1923 a coordinated attempt was made to classify and study the significance of all forms of life present in sewage treatment plants. In this work Hausman, (15) in studying the fauna of a trickling filter, found "that the free-moving forms

such as the free swimming ciliates and worms, increase in numbers as the film on the stones builds up, and that during the slough, these pass out with the filter effluent along with the sloughing film. Their numbers in the film therefore decrease, and simultaneously their numbers in the effluents increase. It is significant to note also that just before sloughing begins the worms (nematodes and annelids) begin to increase. It may be, and very probably is, true that these forms in their continual migrations through and through the film help to loosen the film and thus accelerate the slough.

Again the growth of Opercularia, the stalked, fixed protozoan form, increases greatly after the slough is over, and when the film from the stones is removed so as to permit its free growth. That this form may be important in respect to its excretions into the filter bed is the present judgment of the zoologist."

This worker artificially cultured Opercularia and watched its behavior under the microscope. He found it a very active bacteria feeder "devouring on the average 120 bacteria per minute during its periods of feeding". The organisms next in importance in respect to numbers were the nematodes.

Haenseler, Moore and Gaines (14) studied the fungi and algaê of the trickling filter.

"The surface layers of stones were covered throughout the year with an abundance of green algae, Stigeoclonium, and the blue green algae Oscillatoria. A relatively small amount of fungi was present on the surface of the stones. On the subsurface stones the slimy film was bound together largely by fungi, Beggiatio, filamentous bacteria and stalked protozoa. The principal fungi found in the mycelial stage were Penicillium sp., Pythium sp., Dictyuchus and two unidentified forms, one of which is probably an Oidium. There is a seasonal fluctuation of the fungi, reaching the maximum during the winter months and a minimum during June, July and August. Beggiatio and the filamentous bacteria have a seasonal fluctuation opposite that of fungi, reaching their maximum during the summer and a minimum in winter. Fungous hyphae seem to play an important role in building up and binding together the film on the subsurface stones of the filter bed."

Hotchkiss (17) made a survey of the bacteria responsible for certain biochemical changes in a trickling filter bed.

"The bacterial groups thus studied include proteolytic organisms, organisms responsible for sulphur reductions and oxidations, those concerned with nitrogen transformations and those causing the destruction of cellulose."

"The bacterial population of both Imhoff tanks and sprinkling filters was found to be similar during the winter months and the groups of organisms bore approximately the same numerical relationship. Of the types studied, those present in the highest dilutions of the inoculum, and therefore the predominating organisms, were the proteolytic bacteria and the bacteria concerned with the transformation of nitrogen. The nitrate reducers were somewhat more abundant than the nitrogen oxidizing bacteria in both the sprinkling filter and the Imhoff tank. The bacteria concerned with sulfur changes were less abundant than those concerned with the nitrogen cycle, while cellulose destroyers were found only in low dilutions."

The experimental data presented by this worker seem to indicate that the process of digestion in an Imhoff tank is not entirely anaerobic, and that in the trickling filter is not entirely aerobic.

Considerable further study has been made of the biological life found in trickling filters, particularly by Caub (18), Lackey (20), (21), (22). Rudolfs (23), Frye and Becker (13), and Buswell (7) give a summary of work to date. However, very little new information concerning the significance of the various organisms found has been obtained. Gaultier (19) suggests that Paramecium is an active nitrifier but gives no experimental data to substantiate this claim.

Most authors dealing with sewage treatment mention the presence of sewage flies. Buswell mentions them as a common nuisance and suggests that the species commonly found are Psychoda phalaenoides and Psychoda sexpunctata, but says nothing concerning the significance of the larvae in the biological film in the filter. Headlee and Beckwith (16) describe the life cycle of the fly Psychoda alternata and suggest that 24 hour flooding of the beds may be used as a means of control. These workers also found a small number of *Psychoda cinerea* present in filters.

D. Filter Media

In the early work at the Lawrence Experiment Station coarse gravel was used as a trickling filter medium. During the course of the experimental work at the station, various sizes of coarse gravel, crushed granite, quartzite, trap rock, broken brick, cinders, roofing slate and blast furnace slag were tried. Of all these materials the crushed stone of about one to three inches in size was found most satisfactory, though under certain circumstances some of the other materials were at times more economical.

Since that time numerous other materials have been suggested and tried. Rudolphs (29) reports the operation of four similar sized filters, dosed with domestic sewage at about 2 M.G.A.D. using crushed rock, slag, and gravel, all one and one-half to two and one-half inches in diameter, the fourth filter being made up of layers of one-half inch mesh galvanized screen placed at six inch levels. The results obtained were about as expected; the crushed rock filter gave the most satisfactory operation and purification. Levine (23) reports the use of lath, coarse rock (two to three and one-half inch), gravel, broken tile, cinders, spiral ring packing and corn cobs in experimental filters. Of these materials, small gravel gave good purification but clogged badly; corncobs effected considerable reductions, but were not considered as suitable; lath, coarse cinders and rock were considered as giving very good results. The broken tile gave good purification but disintegrated badly. The tile used had been rejected because of defects and probably would have disintegrated under any circumstances. The spiral ring packing because of the large size (three inch) of the individual rings did not produce as great a purification as the other materials. Greater purification would have been anticipated with smaller sizes of rings.

From the experimental work on trickling filters, and the practical experience in the field, it becomes evident that the desirable characteristics in an ideal filter medium include the following:

1. The material must be inert to sewage, not subject to either chemical or physical action in the filter.

2. The surface of the medium per unit volume should be a maximum, and that surface should not be of the type that is easily coated over and made valueless as in charcoal.

3. The interstice size should be a maximum to allow sloughed particles free passage to the bottom of the filter and out with the effluent.

4. Further it is desirable that the interstice size be uniform throughout the medium.

5. There should be a minimum of restricted openings in

the medium where solids may lodge and eventually clog.

6. It seems desirable that the surface of the medium be slightly rough so as to offer something for the biological film to anchor itself to. It has been found that the film does not adhere readily to a smooth surface.

7. The mechanical strength of the medium should be great enough to allow handling.

8. It is desirable that the weight of the medium per unit volume be low so as not to require too heavy a foundation for the filter.

9. The nature of the medium should be such as to tend toward low manufacturing and installation costs.

III. EXPERIMENTAL

A. Preliminary Laboratory Experiment.

1. Objectives and Experimental Setup.

The previous work on trickling filters appears to indicate that the function of the filter medium is that of furnishing a mechanical support upon which the microbial film may develop. The changes brought about in the sewage incidental to the purification of the sewage are brought about as a result of the life processes of this microbial film. In general this entire process is a biological oxidation process although many other actions occur to effect the whole series of changes.

If the microbial film is responsible for the changes brought about during purification, and the sewage must come into intimate contact with this film, and conditions are to remain essentially aerobic during the process, then it is reasonable to expect that other things being equal, the greater the surface of the film the more rapid, more efficient or more complete the process will become. The greatest surface for a given medium is obtained by decreasing the size of the individual pieces. That is, the finer the particles the more surface is exposed. However another factor, namely that of clogging makes it essential that the interstices be of reasonable size. Whenever the microbial film sloughs, as it does at times, the sloughed material must have a free path out of the filter, otherwise clogging is imminent. In this connection uniformity of size and shape of medium have marked advantages.

Although not definitely established it is generally held that the effective surface per unit volume, and the free air space of the filter medium are the two largest factors determining the capacity and operating characteristics of a biological filter, treating a given waste. It is also held that uniformity of size and shape of the medium are vefy desirable. The maximum interstice size for a given size of medium is also desirable.

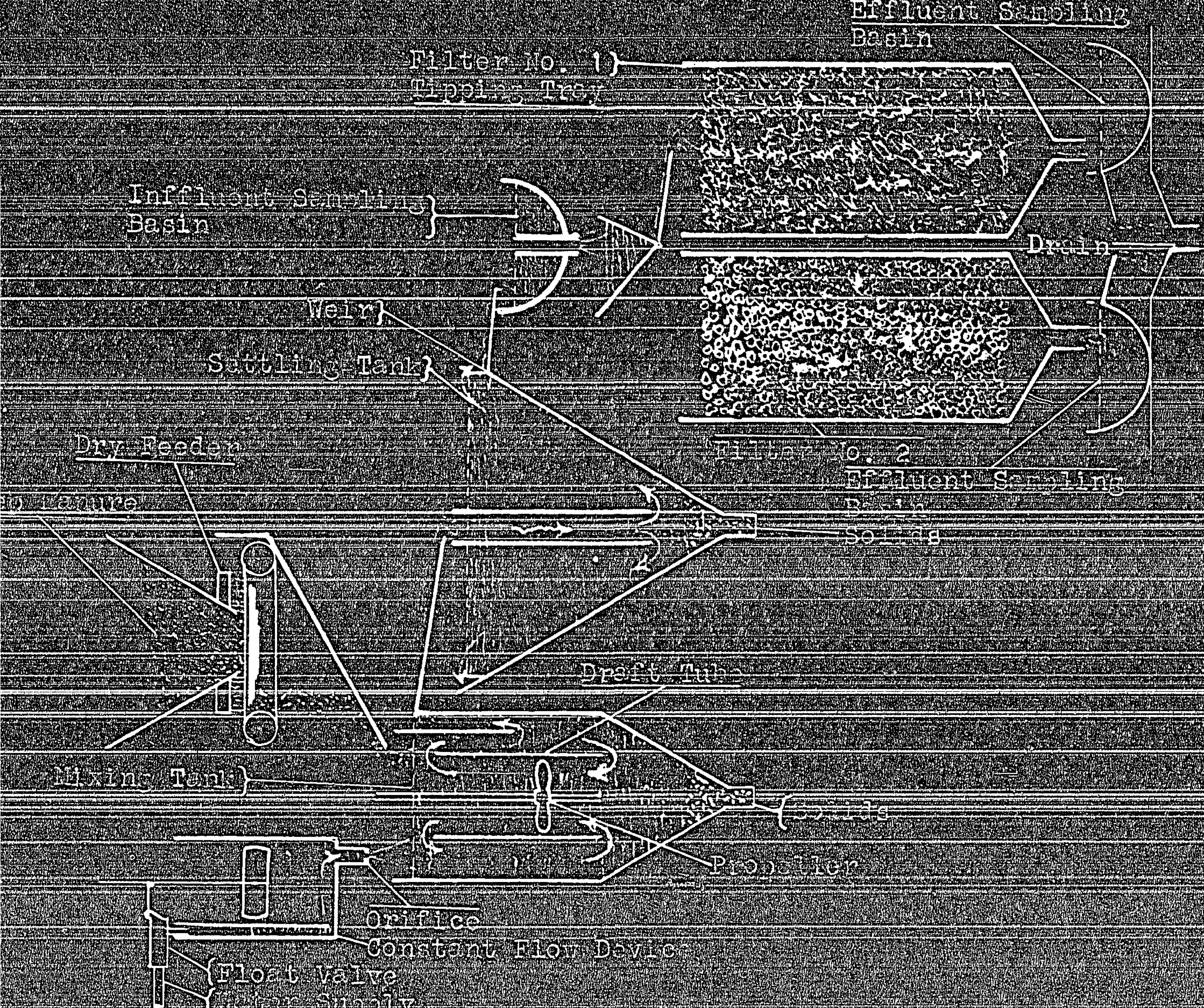
Properly modified ceramic absorption tower packing, such as used in the chemical industry would have many of these desirable characteristics. One such form which suggests itself as being readily adaptable to service as a trickling filter medium is that of Raschig rings. Raschig rings are simple geometric shapes, a hollow cylinder of equal length and diameter. The wall thickness of the cylinder is only great enough to provide mechanical stability.

For sake of comparison, granite such as is commonly used in trickling filters has 20 to 30 square feet of surface per cubic foot of medium with about 40 per cent freeair space. One-inch Raschig rings, for example, have 52 square feet of surface per cubic foot of medium with 60 to 70 per cent free air space. The interstice sizes in those two media are estimated to be about equal. Raschig rings because of the method of manufacture are uniform in size and shape. Ceramic material is well known for its resistance to attack by sewage or other organic material. Ceramic products have considerable structural strength and stability. A bed of Raschig rings is self-sustaining up to 40 or more feet in depth, being used up to that depth in the chemical industry.

A preliminary experimental plant was built and operated to obtain information concerning the operating characteristics of a ceramic filter medium. A schematic diagram of this experimental plant is shown in Fig. 1. The plant included two experimental filters two feet square in horizontal area and six feet in depth. Galvanized iron tanks supported on angle iron legs were used as filter cases. One to three-inch crushed South Dakota quartzite was the medium used in the control filter. This material is identical to that customarily used in trickling filters throughout the state. One-inch Raschig rings were used as the filter medium in the other filter. The one-inch Raschig rings were made in the Ceramic Engineering Laboratories under the direction of Professor Paul Cox. Iowa clays were used as the raw material for the rings. The filter media were supported at the bottom of the filter by a wood grid, with over 50 per cent free air space. The experi-

Fig 1 SCHEMATIC DIAGRAM OF SETUP FOR PRELIMINARY EXPERIMENT

Drawing No. 3. Drawn 1-12-33 by RHL.



mental filters were dosed with a synthetic waste produced continuously. The synthetic waste was produced, first from dried sheep manure and water, and later from a mixture of dried sheep manure and milk powder and water. The dried sheep manure or dried sheep manure milk powder mixture was fed into a mixing tank by means of a dry chemical feeder of the drag chain type. Water discharged into the mixing tank from an orifice in the botto of a constant level tank. Water from the college water mains was used for production of the synthetic waste. The mixing tank was fitted with a motor driven propeller in a draft tube. This mixing device prevented the settling out of any save the largest gravel particles in the bottom of the mixing tank. The mixed waste was settled for one hour (theoretical time) in a cone shaped settling tank fitted with a circular weir type of discharge.

The synthetic waste was applied to the filters by means of a motor controlled tipping trough and perforated metal distributing trays. The distributing trays are not shown on the schematic diagram. The trays were placed about six inches above the filter medium, and sufficiently raised above the filter cases to allow free ventilation from the top of the filters. The effluents from the filters were collected in a sloping tray suspended a few inches below the bottom of the filter cases.

Motor operated samplers collected a small sample of the influent and each of the effluents every five minutes. In 24 hours a gallon composite sample was collected in this manner. The samplers were spoonlike affairs which dipped into the appropriate sampling basin at five minute intervals and dipped out a small sample placing it into a suitable container.

Soon after the plant was placed into operation difficulty was experienced due to floating solids in the synthetic waste. These sawdust-like particles clogged the perforated metal distributing trays. In order to remove these coarse floating solids a traveling belt screening device was interposed between the settling tank and the influent sampling basin. A set of motor driven rollers between which a fine cloth belt operated, satisfactorily removed most of the coarse floating particles. The cloth belt was continually cleaned by means of a needle spray directed on the bottom side of the belt. The residue removed from the water fell into a collected tray beneath the belt. This screening device is not shown on the schematic diagram. A test of the floating particles removed by this screen indicates that they were mostly relatively inert cellulosic material, contributing little to the concentration of the waste. The settled solids were removed from the settling tank once every day, and from the mixing tank once every week. The solids removed from the mixing tank were principally white gravel and particles of coal, all one-eighth inch or larger in diameter.

2. Method of Operation.

During the entire operation of this experimental plant the rate of application of the waste was maintained at 2 M.G.A.D. with a six minute dosing cycle. The rate of application was dependent upon the flow of water into the mixing tank. This was maintained constant by maintaining a constant head of water on the orifice by means of a float valve, and by occasional cleaning of the orifice. Since water from the college water main was being used, the orifice did not require cleaning save at rare intervals. The dosing cycle was maintained constant by means of a motor operated mechanism which permitted the tipping trough to tip only at certain intervals, every three minutes in this case. The filters were in this manner dosed alternately, allowing each filter to be dosed once every six minutes.

The concentration of the waste was determined by the rate of feed of sheep manure into the mixing tank. A commercial dried sheep manure, such as is commonly used for a lawn fertilizer, was employed to produce the synthetic waste. It was hoped that a very uniform waste might be produced from this material. The dried sheep manure was placed in the hopper of the motor operated chemical dry feeder and was fed continuously.

When the plant was first put into operation, only dried sheep manure was fed. This produced a waste of lower concentration than was desired. It was found impractical to feed enough dried sheep manure to obtain a desired high concentration of waste. In order to increase the concentration of the waste, spray dried, skim milk powder was mixed with the dried sheep manure and the mixture fed by means of the dry chemical feeder. Special tests indicated that very thorough mixing of the milk powder and sheep manure was necessary to insure a uniform concentration of waste. The dried sheep manure and the milk powder were weighed and then mixed for a number of hours (often 24 hours) in a revolving barrel fitted with mixing paddles on the inside surface.

3. Analyses and Analytical Methods.

All analyses were made according to the methods given in Standard Methods (1) unless otherwise stated. Determinations of biochemical oxygen demand, oxygen consumed, relative stability, dissolved oxygen, free ammonia, nitrites, nitrates and pH were made on the 24 hour composite samples, except where otherwise noted. Solids determinations were made on chloroformed weekly composite samples.

Biochemical oxygen demand determinations were made by the dilution method using aerated distilled water buffered with 300 p.p.m. of sodium bicarbonate as diluent. A 5-day incubation period at 20 degrees Centigrade was used.

The procedure given by standard methods was followed for the oxygen consumed values, except that a more concentrated potassium permanganate solution was used. Comparative determinations indicated that for the given waste the results obtained are comparable with results obtained when using the concentrations suggested by standard methods.

Free ammonia was determined by direct nesslerization, with an occasional check run being made with distillation and nesslerization. Nitrates were determined by the reduction method. A LaMotte comparator set was used to obtain pH values.

4. Results.

The operating data and log of plant operation are given in Table No. 1. A plot of the operating data is shown in Fig. 2. The operation of the plant may be divided into three operating periods on the basis of the concentration of the applied waste. During the period from May 23, 1935, until June 20, only dried sheep manure was used for waste production. During this period the average B.O.D. concentration of the applied waste was 117 p.p.m. During the second operation period from June 21, until August 25, a mixture of one pound of milk powder to 16 pounds of dried sheep manure was applied and the average B.O.D. concentration of the applied waste was 567 p.p.m. During the last or third operating period, from August 26 until September 28, a mixture of one

Trickling Filter Studies - Data Sheet No 1

Date	Sample	Data Sheet No	Feed: Material	Feed: lb added during day	Feed: Feeder rev/day	Feed: Dosing cycle	BOD: I	BOD: R	BOD: G	BOD Reduct: R	BOD Reduct: G	Oxygen Consumed: I	Oxygen Consumed: R	Oxygen Consumed: G	O.C. Reduct: R	O.C. Reduct: G	Relative Stability: R	Relative Stability: G
						sec	ppm	ppm	ppm	%	%	ppm	ppm	ppm	%	%	%	%
May 23	G	1		18		364	122	12		[illegible]							99	50
24		2		11	[illegible]	352												
25		3		22	[illegible]	358												
26	C	4			[illegible]	361	114	17	21	[illegible]	81.6						95	80
27	G	5			3140		[illegible]	[illegible]	23	[illegible]	[illegible]						[illegible]	[illegible]
28		6		16	3300	360												
29		7			6020													
30		8		9	6010	372												
31	C	9		22	6040		54	12	26	77.8	51.8						96	68
31	G	10					[illegible]											
31	WC	11					76	14	16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	42.5	42.5		
Je 1	C	12		22	5770	367	122	12	12	90	90						68	68
1	G	13					112	22	22	80.4	80.4						60	60
2		14		16														
[illegible]		15		[illegible]	6020													
4		16		[illegible]	6010													
5	C	17	Dried Sheep Manure	[illegible]	6010	[illegible]	124	[illegible]	[illegible]	[illegible]	[illegible]							
5	G	18					144	27	[illegible]	80.1	84.5						[illegible]	[illegible]
6	C	19		[illegible]	5740	367	144	[illegible]	[illegible]	95.0	91.0						[illegible]	[illegible]
6	G	20					172	27	[illegible]	[illegible]	[illegible]						[illegible]	[illegible]
7		21		[illegible]	5990	359												
8		[illegible]			5798	392												
9	C	[illegible]				367	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]						[illegible]	[illegible]
9	[illegible]	[illegible]						[illegible]	[illegible]								[illegible]	[illegible]
10	C	25		16		360	144	14	13	[illegible]	88.6						68	68
11		26		16														
12		27		16														
14	C	28			5780	370	[illegible]	[illegible]	15	91	[illegible]	[illegible]	[illegible]	[illegible]	40.4	37.8	99	87
14	WC	29					130	344	344			274	165	168	39.8	38.6		
14	G	30					270	27	36	[illegible]	86	248	116	[illegible]	69.7	68.5	[illegible]	[illegible]
15	C	31		[illegible]	6190		[illegible]	18	24	[illegible]	76						[illegible]	[illegible]
[illegible]		32		[illegible]	5960													
[illegible]	C	[illegible]		[illegible]	[illegible]	[illegible]	138	12	13								99	92

...sumed		Relative Stability		Total Solids									Suspended Solids								
...educt				Total			Volatile			% Volatile			Total			Volatile			% Volati...		
R	G	R	G	I	R	G	I	R	G	I	R	G	I	R	G	I	R	G	I	R	G
%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	%	%	%
		99	50																		
		95	80																		
		[illegible]	[illegible]																		
		96	68																		
25	425			[illegible]	1174	1124	431	404	[illegible]	38.5	37.3	39.3	[illegible]	[illegible]							
		[illegible]	68																		
		[illegible]	60																		
		[illegible]	[illegible]																		
		[illegible]	60																		
		68	68																		
0.4	37.8	99	87																		
18	38.6			1088	1172	1170	500	444	576	43.2	37.9	44.0	[illegible]	[illegible]	[illegible]						
97	68.5	[illegible]	[illegible]	1168			484			45.6			[illegible]								
		[illegible]	60																		
		[illegible]	[illegible]																		

...ded Solids					Dissolved Oxygen			Free NH3			Nitrite		Nitrates			pH			Temperature		
...atile		Non-volatile																	Influent	Effluent	
R	S	I	R	S	I	R	S	I	R	S	K	S	I	R	S	I	R	S			
ppm	ppm	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm						
																			19	20.5	
																			18.5		2
																			19.5	20	2
																			–		2
																			17		2
																					1
																			17	17	2
																			18		2
																			[illegible]	[illegible]	28
																			[illegible]	[illegible]	[illegible]
																7.2	7.1	7.5			3
																7.4	[illegible]	[illegible]			
																			17		

Table

	[illegible]			[illegible]		[illegible]		Notes:
	19	20.5						Feed belt broken. Float counterbalance installed. Rate of feed [illegible]
	18.5		20.5					Screen belt [illegible]
	18.5	20	20.5					
			23					[illegible] of spray for cleaning screen increased
	17		23	+	+			Bridging in feeder - wet manure. Film increasi[illegible]
			19					" " " " " " " Screen belt st[illegible]
	17	17	20.5					" " " " " " " Feeder cleaned
	18		23					" " " " " " Straw in manure
								Sample taken to show effect of bridging i[illegible]
	17		21					Bridging in feeder [illegible]
								" " [illegible]
	[illegible]	20	20.5					[illegible]
			21	N	N			[illegible]
[illegible]			25	[illegible]	[illegible]			Film increasing. Flies decreasing.
								Bridging in feeder
								[illegible]
								[illegible]
	[illegible]	[illegible]	24	N	N			[illegible]
								[illegible] off during nite
			21					Bridging in feeder
	17		21					An attempt was made to use finely pulver[illegible]
								occurred in feeder. Very irregular operati[illegible]
								[illegible] pulverized [illegible] manure fed. 21 lbs fed
			24					Flies [illegible] manure ground in USDA [illegible]
								[illegible]
	17		21					[illegible]

Table No. I -32-

-5:

broken. Float counterbalance installed. Rate of feed increased

belt broken

spray for cleaning [illegible]

ng in feeder-wet manure. Film increasing. Screen belt broken

" " " " " " Screen belt stuck.

" " " " " " Feeder cleaned and manure dried

" " " " Straw in manure.

[illegible]

[illegible]

[illegible]

[illegible]

increasing. Flies decreasing.

ng in feeder.

[illegible]

[illegible]

[illegible]

off during [illegible]

ing in feeder

[illegible] finely pulverized sheep manure bridging

in feeder. Very irregular operation.

[illegible] manure fed. 2 lbs fed in 8 hrs. (ball mill pulverized)

[illegible] ground in USDA hammermill to great size reduction.

[illegible]

[illegible]

6	C	19	6	[illegible]	5940	367	144	[illegible]	16	93.0	91.0						[illegible]	[illegible]
6	G	20	Σ				172	27	22	94.0	87.2						75	70
7		21		16	5930	359												
8		22			5198	362												
9	C	[illegible]				364	[illegible]	[illegible]	[illegible]	92.1	77.5						[illegible]	[illegible]
9								[illegible]	[illegible]									[illegible]
10	C	25		16		[illegible]	114	14	13	97.1	86.6						68	68
11		26		16														
12		27		16														
14	C	28			5780	370	[illegible]	[illegible]	[illegible]	91	[illegible]	[illegible]	[illegible]	[illegible]	40.4	37.8	19	37
14	WC	29					130	64+	64+			274	165	68	39.8	38.6		
14	G	30					270	27	36	10	[illegible]	648	176	-14	69.7	68.5	[illegible]	-1
15	C	31		[illegible]	5775		110	[illegible]	[illegible]	[illegible]	72						[illegible]	[illegible]
16		32		24	5960													
17	C	[illegible]		[illegible]	5920	[illegible]	110	12	13								99	93
17	G	34					76	23	25	97.7	87.1						72	87
18		35		[illegible]	5910													
19	C	36		16	5980	[illegible]	37	7	11	91.1	86	235	115	120	51.1	48.9	99	76
20	C	37		16	5970	361	112	11	20	93.2	92.1	390	184	201	44.2	39.1	102	99
21		38		20	5960	[illegible]	100	8	12	[illegible]	[illegible]	480	[illegible]	[illegible]	50.6	52.3	[illegible]	37
22	C	39		[illegible]	[illegible]	[illegible]	515	17	36	97.1	93.4	[illegible]	162	172	56.2	53.8	21	21
22	G	40					(310)	[illegible]	11	89.0	86.0	[illegible]	[illegible]	[illegible]	55.8	36.8	[illegible]	73
23	[illegible]	41		24		[illegible]	340	18	20	94.7	94.1	[illegible]	185	[illegible]	56.9	57.1	21	21
23	G	42					325	25	40	[illegible]	[illegible]	369	182	147	64.2	60.1	37	21
23	WC	43																
24	G	44		24	5922	367	[illegible]	26	20+	97.8	86.7						21	21
25	[illegible]	45		24	5904	363	[illegible]	[illegible]	[illegible]			[illegible]	[illegible]		54.7	51.6	[illegible]	[illegible]
26	G	46		24	5980	[illegible]	440	[illegible]	26+			479	217	218	56.9	51.9	21	21
27	G	47		24	5960	359	775	28+	26+			504	213	245	57.7	51.4	21	21
28	G	48		24	5970	362	490	27	25+	94.5		459	187	220	59.2	52.0	37	21
29	G	49		22	5950	362	506	27+	20+								21	21
30	G	50		[illegible]	5908	[illegible]	470	17	[illegible]	91.6	[illegible]	429	184	184	56.2	56.2	21	21
30	C	51					390	18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	204	52.2	40.9	68	21
30	WC	52										381	187	184	50.9	51.7		
Jl 1	G	53		22	5757	[illegible]	[illegible]	40	26+	72.4	[illegible]	[illegible]	[illegible]	[illegible]	59.0	54.5	[illegible]	21
2	G	54	Σ	24	5925	362	470	20	22	95.7	[illegible]	408	162	147	61.8	64.0	67	37
2	C	55					450	18	18	96.5	95.8	408	185	175	55.9	52.2	75	37
3	G	56		[illegible]	5960	353	[illegible]	50	67	90.6	87.4	477	207	253	56.6	47.0	21	21
4	G	57			5959	[illegible]	410	[illegible]	[illegible]	96.5	96.6	[illegible]	[illegible]	[illegible]	55.2	50.9	21	21
5	G	58		23	5950	[illegible]	[illegible]	43	24+	91.1	98.7	[illegible]	[illegible]	[illegible]	56.1	49.3	37	21
6	G	59		10.5	5959	362	[illegible]	58	[illegible]	97.9		[illegible]	187	[illegible]	56.7	48.4	67.0	21
7	G	60			5712	[illegible]	[illegible]	[illegible]	[illegible]	87.0	[illegible]	[illegible]	[illegible]	[illegible]	43.2	37.2	[illegible]	58
8	G	61	Σ	12	5996	357	540	61	58+			592	256	296	56.8	50.0	21	37

		[illegible]	[illegible]												
		[illegible]	[illegible]												
		[illegible]	[illegible]												
		[illegible]	[illegible]												
		[illegible]	68												
40.4	37.8	[illegible]	87												
39.8	38.6			1084	[illegible]	[illegible]	[illegible]	447	[illegible]	43.2	37.9	44.0	[illegible]	[illegible]	[illegible]
69.7	68.5	[illegible]	[illegible]	1158			584			45.6			[illegible]		
		[illegible]	[illegible]												
		77	72												
		72	87												
51.1	48.9	77	[illegible]												
44.2	39.1	100	[illegible]												
55.6	52.3	[illegible]	[illegible]												
56.2	53.8	21	21												
55.8	53.8	[illegible]	[illegible]												
56.9	57.1	21	21												
64.2	60.1	37	21	1626			[illegible]			41.2					
				1674	1717	[illegible]	862	657	680	51.5	46.3	40.8			
		21	21												
54.1	51.6	[illegible]	21												
56.9	57.9	21	21												
57.7	57.4	21	21												
59.2	52.0	37	21												
		21	21												
56.2	56.2	21	21												
52.2	40.9	68	21	[illegible]	[illegible]	1569	827		[illegible]	51.1		51.8	[illegible]	[illegible]	[illegible]
50.9	51.7			2018	1648	1696	1442	1148	1085	71.8	69.7	64.1	[illegible]	[illegible]	[illegible]
59.0	54.5	21	21												
61.8	64.0	37	37												
55.9	52.2	75	37												
56.6	47.0	37	21												
55.2	50.9	21	37												
56.1	49.3	37	21												
56.7	48.4	[illegible]	21												
43.2	37.2	[illegible]	[illegible]												
56.8	52.0	21	37												

			1.1	1.2						7.2	7.7	7.8			32
		1.0	1.5	2.2						7.4	[illegible]	[illegible]			
													[illegible]	24	31
										7.2	7.7	7.7			24
										7.8	8.2	8.1			
										[illegible]	[illegible]	7.7	22	24	32
										6.8	7.8	7.7			
										7.3	8.0	8.[illegible]			
										6.[illegible]	[illegible]	7.7	21	[illegible]	33
										7.5	8.1	8.0			
								1.7	1.0	7.4	8.1	8.0	[illegible]	23	30
										7.2	8.2	7.8	[illegible]	27	25
										7.1	8.0	7.1	25		27
					0.16	0.16	0	1.0	0.5	7.0	8.1	7.9	22		29
					0.3	0.3				7.0	8.0	7.9	21	24	27
1.0	[illegible]				0.13	1.12	0.7	[illegible]	[illegible]				23	[illegible]	24.5
					[illegible]	0.3		1.0	[illegible]	7.0	8.1	7.7	[illegible]	[illegible]	30
					0.26	0.1		1.2	0.5	6.8	7.5	7.7			
					[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	7.5			
													22	27	25
										[illegible]	7.7	7.6	21	24.5	[illegible]
					[illegible]	[illegible]				[illegible]	7.[illegible]	7.5	[illegible]		[illegible]
										7.[illegible]	[illegible]	[illegible]	[illegible]		[illegible]

					Remarks
		32		✓	Film increasing Flies decreasing
					Bridging in feeder
					Trip pipe [illegible]
					[illegible] Feeder [illegible]
					[illegible] off during nite
					Bridging in feeder
					[illegible] finely pulverize
					occurred in feeder. Very irregular operation.
					[illegible] 2 lbs fed in
					[illegible] USDA [illegible]
					[illegible] belt [illegible]
					[illegible]
21		33			[illegible] Feeder [illegible]
		30			Film [illegible] Filter [illegible]
		26		+	
		29	+	+	
		27			
		245	+	++	Good
					[illegible] solids [illegible]
	242	28	+	+	Feeder [illegible]
	285	260			[illegible]

increasing. Flies decreasing.

...ing in feeder.

[illegible]

[illegible] feeder [illegible]

[illegible]

... off during nite.

...ing in feeder

[illegible] finely pulverized sheep manure bridging

... in feeder. Very irregular operation.

... pulverized sheep manure ... 2 lbs fed in 6 hrs. (ball mill pulverized)

... sheep manure ground in USDA hammer mill, no great size reduction.

[illegible] belt [illegible]

[illegible]

[illegible] SM-MF test started

[illegible]

[illegible] milk powder [illegible] in feeder

[illegible] on filter effluent.

[illegible] feeder [illegible]

[illegible] filter flies increasing.

[illegible]

BOD's

[illegible]

[illegible] solids ... made on [illegible] sample

[illegible] SM-MF mixture, mixed in tumbling barrel [illegible] hours.

[illegible] mixture [illegible] feeds faster

[illegible]

[illegible] ball of wool in [illegible] very cloudy

...g in feeder, ball of wool in manure

	[illegible]	G	77		24	6012	367	600	26	60+	898	92-						21	21
	25	G	45		24	6004	363	572	32+	30+			459	[illegible]	[illegible]	547	51.6	21	21
	26	G	46		24	5980	[illegible]	280+	32+	28+			474	224	238	569	51.9	21	21
	27	G	47		24	5960	363	715	28+	26+			504	213	245	57.7	51.4	21	21
	28	G	48		24	5970	362	490	27	26+	94.5		459	187	220	59.2	52.0	37	21
	29	G	49		24	5950	362	605	27+	20+								21	21
	[illegible]	G	50		22	5908	[illegible]	470	27	[illegible]	91.6	[illegible]	420	184	184	56.2	56.2	21	21
	30	G	51					570	18	20	[illegible]	97.1	[illegible]	160	201	52.2	40.9	58	21
	30	WC	52										381	187	184	50.9	51.7		
Jl	1	G	53		24	5757	[illegible]	[illegible]	40	35+	92.4	[illegible]	[illegible]	157	210	59.0	54.5	21	21
	2	G	54		24	5920	362	470	20	35	95.7	[illegible]	498	164	144	61.8	64.0	67	37
	2	C	55					435	16	18	92.5	95.2	456	180	170	55.9	52.2	70	67
	[illegible]	G	56		[illegible]	5760	355	600	59	67	71.6	87.4	774	274	255	56.6	47.0	[illegible]	[illegible]
	[illegible]	[illegible]	57		[illegible]	5969		[illegible]	[illegible]	[illegible]	[illegible]	96.6	[illegible]	[illegible]	[illegible]	55.2	50.9	21	21
	[illegible]	G	58		[illegible]	5950	[illegible]	650	42	42+	97.1	98.7-	[illegible]	[illegible]	[illegible]	56.1	49.3	67	21
	6	G	59		12	5959	362	605	56	45	90.1		462	184	223	56.7	48.4	60	21
	7	[illegible]	60			5772	[illegible]	[illegible]	[illegible]	[illegible]	87.0	[illegible]	[illegible]	[illegible]	[illegible]	43.2	37.2	70	[illegible]
	8	G	61		12	5776	357	640	61+	58+			592	256	296	56.8	50.0	21	37
	9	G	62		30	5830	364	620	56	67	[illegible]	[illegible]	678	416	368	35.8	43.2	21	60
	10	G	63		20	5940	358	710	70	69	90.1	90.2	632	278	283	56.0	55.2	37	60
	11	G	64		30	5928		630	112	[illegible]	78.7	[illegible]	[illegible]	[illegible]	[illegible]	51.6	51.8	70	70
	11	WC	65			5712							[illegible]	284	312	44.9	39.0		
	[illegible]	G	66		[illegible]	5712		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	56.8	57.1	[illegible]	75
	[illegible]	[illegible]	[illegible]		[illegible]	5773		[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]	42.4	42.9	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]		[illegible]	5923		[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	214	310	67.7	63.2	87	[illegible]
	[illegible]	[illegible]	[illegible]		[illegible]			[illegible]					[illegible]						
	[illegible]	[illegible]	71		[illegible]			[illegible]											
	17	G	71		[illegible]		327	440	71	[illegible]	70.7	90.1	[illegible]	[illegible]	[illegible]	67.5	61.7	60	63
	[illegible]	[illegible]	72		22	6100	354	520	35	25	93.3	95.2	560	234	242	58.9	57.5	87	84
	17	WC	73																
	18	WC	74										[illegible]	[illegible]	244	44.5	44.5		
	19	G	75		30	5778		430	77	38	81.6	91.2	534	[illegible]	244	53.2	51.6	98	90
	20	G	76			5909	358	470	66	41	92.7	[illegible]	536	224	238	58.2	55.6	77	75

	—	21	21																	
54.7	51.6	21	21																	
56.9	51.9	21	21																	
57.7	51.4	21	21																	
59.2	52.0	37	21																	
		21	21																	
56.2	56.2	21	21																	
52.2	50.9	[illegible]	21	[illegible]	[illegible]	65.1	82.7		[illegible]	51.1		51.8	[illegible]	[illegible]	[illegible]	[illegible]				
50.9	51.7			201.8	164.8	129.6	147.2	114.8	108.?	71.8	69.7	64.1	[illegible]	[illegible]	[illegible]	[illegible]				
59.0	54.5	21	21																	
61.8	64.0	37	37																	
55.9	52.2	75	37																	
56.6	47.0	37	[illegible]																	
55.2	50.9	21	37																	
56.1	49.3	37	21																	
56.7	48.4	50	21																	
43.2	37.2	97	42																	
55.8	50.0	21	37																	
35.8	43.2	21	50																	
56.0	56.2	37	60																	
51.6	51.8	73	75																	
41.9	39.0			[illegible]	134	[illegible]	[illegible]	[illegible]	[illegible]	60.5	45.6	70.3	[illegible]	[illegible]	[illegible]					
56.8	57.1	[illegible]	[illegible]																	
42.4	42.9	[illegible]	[illegible]																	
57.7	53.2	[illegible]	[illegible]																	
67.5	61.7	62	62																	
58.9	57.5	87	84																	
				[illegible]	147.1	127.1		[illegible]	[illegible]		46.0	51.6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	80.8	73.9
44.5	44.5			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	58.2	40.4	37.3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	61.3	77.2
53.2	51.6	96	70																	
58.2	55.6	99	98																	

													1.2	1.0	7.2	8.1	8.0	[illegible]	25	30
															[illegible]	8.0	[illegible]	[illegible]	[illegible]	25
															7.1	8.0	7.7	[illegible]		29
										[illegible]	[illegible]	0	1.0	0.5	7.0	8.1	7.9	[illegible]		29
										0.9	0.9				7.0	8.0	7.7	21	24	27
				0	0	0									6.9	7.9	7.8	22	24.5	26.5
				0	0.4	1.50									7.0	8.0	[illegible]	21	23.5	25
				0	[illegible]	[illegible]									[illegible]	8.1	8.0	22	[illegible]	[illegible]
				0	1.0	0.5												22	22.6	20
[illegible]	80.8	73.9	74.3																	
[illegible]	67.3	77.2	56.8																	
															6.8	8.0	7.8	23	24.5	[illegible]
															[illegible]	7.7	7.7	24	[illegible]	28

	8.1	23	25	30				Film [illegible] Filter flies
	[illegible]	[illegible]	[illegible]	28	+	+		[illegible] operation. Effluent [illegible]
	[illegible]	[illegible]		27	+	+		
	7.9	[illegible]		27	+	+		
	7.9	21	24	27				
		27	[illegible]	245	+	++		Odor [illegible]
	7.7	[illegible]	[illegible]	[illegible]				[illegible] Filter flies [illegible]
	7.7							[illegible] solids [illegible]
	7.5							
		[illegible]	240	25	+	+		[illegible]
	7.5	21	235	[illegible]				[illegible] very [illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
								[illegible] of wool [illegible]
9	7.8	22	245	265				Bridging in feeder. balls of wool in manure
[illegible]	[illegible]	21	235	25	+++	++		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		Film increasing. R very cloudy. Flies [illegible]
[illegible]	7.7	[illegible]	[illegible]	[illegible]	++			Tipping tray stuck.
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	[illegible]	[illegible]			[illegible]			Very irregular operation. Belts slipped, feede[illegible]
1	8.0	22	[illegible]	[illegible]	[illegible]			Filter operation normal
				[illegible]				Feeder belt broken
								[illegible] belt broken. very irregular [illegible]
	[illegible]	[illegible]			[illegible]	[illegible]		
		[illegible]	235	[illegible]	N	N		
								[illegible]
0	7.8	23	240	25				
[illegible]	7.9	[illegible]	[illegible]	28				

[illegible] in color. Filter flies increasing.
[illegible] Effluent [illegible]

[illegible]
" Filter flies increase [illegible]
" [illegible] solids [illegible] [illegible] sample

[illegible] feeding [illegible] hrs.
[illegible] new [illegible] faster

[illegible]

[illegible] wool [illegible] very cloudy

[illegible] in feeder, ball of wool in manure

increasing. R very cloudy. Flies increasing
ing tray stuck.

Irregular operation. Belts slipped, feeder bridged, screen stopped, orifice clogged
[illegible] operation normal
der belt broken
[illegible] very irregular operation

[illegible] #60

Trickling Filter Studies — Data Sheet No 2

Date	Sample	Data Sheet #	Feed: Material	Feed: lb added during day	Feed: Feeder rev/day	Feed: Dosing cycle	BOD I	BOD R	BOD G	BOD Reduction R	BOD Reduction G	Oxygen Consumed I	Oxygen Consumed R	Oxygen Consumed G	Oxygen Consumed Reduct. R	Oxygen Consumed Reduct. G	Relative Stability R	Relative Stability G	I
						sec	ppm	ppm	ppm	%	%	ppm	ppm	ppm	%	%	%	%	pp
July 21		77	↑	18		357													
22	G	78		24		359	400	66	46	83.6	88.5	460	254	296	44.8	35.6	100	21	
23	G	79		27.5	5720		270	15	41	94.4	84.8	440	232	236	47.2	46.4	100	100	
24	G	80		29	5880		250	28	37	88.8	85.2	556	226	248			96	57	
25	G	81		30	5933	358	180	26	24	85.6	86.7	460	178	180	61.3	60.8	100	100	
25	WC	82																	21
25	WC	83										536	236	220	56.0	58.9			22
26	G	84		7.5	5936	359	260	21	23	91.9	91.1	416	160	160	61.5	61.5	100	100	
27	G	85		30	5940	361	420	31	44	92.6	89.5	416	216	202	51.8	48.6	96	76	
28	G	86		32	5700	359	220	28	26	87.3	88.2	420	178	205	57.4	51.8	100	100	
29	G	87		32	5900		560	38	40	93.2	92.9	704	276	286	60.8	59.4	77	84	
30	C	88		32	5820		430	13	13	97	97	600	246	276	59.0	54.0	98	92	
31	G	89		35			640	47	50	92.7	92.2	712	254	264	64.1	62.9	76	72	
Aug 1	G	90a		17			1200	112+	112+			1340	372	380	72.6	71.0	21	21	40
1	WC	90b										624	268	282	57.0	54.8			22
2	G	91		36			670	35	62	94.8	90.7	990	282	292	71.5	70.5	20	37	24
3	G	92		34	6192	358	1030	26	29	97.5	97.2	1340	452	460	66.3	65.7	97	76	
4	G	93		20	6216	360	700	18	32	97.4	95.4	1120	160	202	85.7	82.0	100	75	
5	G	94		49	6160	359	700	32	76	95.4	89.1	1200	268	300	77.7	75.0	30	11	
6	G	95		33	6122	362	690	35	140+	94.9		1210	284	340	76.5	71.9	75	21	
7	G	96		41.5	6090	360	790	42	65	94.7	91.8	1000	280	304	72.0	69.6	97	11	
8	G	97a		41	6273		810	34	112	95.8	86.2	1270	284	322	77.6	74.6	80	21	
8	WC	97b										970	290	296	70.1	69.5			22
9	G	98		34	6004		650	47	98	92.8	84.9	1470	274	316	81.4	78.5	94	21	22
10	G	99		25	6070		670	39	97	94.2	85.9	1260	276	280	78.2	76.2	21	21	
11	G	100		40	5370		570	18	13	96.8	97.7	1000	158	200	84.2	80.0	100	100	
11	C	101					525	18	27	96.6	94.9	660	236	234	64.2	64.5	98	50	
12	G	102		36	6045		824	55	49	93.3	94.0	1116	262	296	76.4	73.3	21	21	
13	G	103		30	6020		670	65	38	90.3	94.3	1120	274	268	75.5	76.1	21	21	
14	G	104		36	6060		750	42	41	94.4	94.5	1060	262	264	75.3	75.1	21	21	25
15	G	105		35	6259		740	45	49	93.9	93.4	630	286	260	54.6	58.7	21	21	24
15	WC	106					585	60	59	89.7	89.9	470	262	268	44.2	43.0			27

t No 2

umed		Relative Stability		Total Solids									Suspended Solids							
educt.				Total			Volatile			% Volatile			Total			Volatile			% Volati	
R	G	R	G	I	R	G	I	R	G	I	R	G	I	R	G	I	R	G	I	R
%	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	%	%
[illegible]	35.6	100	21																	
17.2	40.4	100	100																	
		96	57																	
61.5	60.8	100	100																	
				2105	1572	1571	1041	[illegible]	[illegible]	49.5	41.2	36.7	149	136	[illegible]	114	86	76	76.6	63.2
56.0	58.9			2200		1606			576			32.1	341	106	177	223	67	119	65.5	63.2
61.5	61.5	100	100																	
51.8	48.5	96	[illegible]																	
57.4	57.8	[illegible]	[illegible]																	
60.8	[illegible]	97	84																	
59.0	57.0	98	92																	
67.1	62.7	96+	[illegible]																	
[illegible]	71.0	21-	21-	[illegible]	2018		2018			90.4										
57.0	[illegible]			[illegible]	1984	1911	[illegible]	[illegible]	[illegible]	48.2	35.2	39.6	191	464	402	[illegible]	[illegible]	265	66.5	65.7
[illegible]	[illegible]	[illegible]	37	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	648	65.9	39.8	36.6	286	464	400	191	311	266	68.8	66.2
66.3	65.7	97	75																	
85.7	82.0	100	75																	
77.7	75.0	30	11																	
76.5	71.9	75	21																	
72.0	69.6	97	11																	
77.6	74.6	80	21																	
70.1	69.5			2262	1580	1921	1176	580	558	52.0	36.7	29.0	438	685	393	278	405	248	53.4	59.1
81.4	78.5	94	21	2256	1683	1907	1065	664	717	47.2	39.5	37.4	698	550	422	450	357	213	64.5	64.9
78.2	75.2	21	21																	
83.2	80.0	100	100																	
67.2	64.5	98	60																	
76.4	73.3	21	21																	
75.5	76.1	21	21																	
75.3	75.1	21	21	2570	1978	1865														
54.5	58.7	21	21	2481	1814	1860		674			37.4									
44.2	43.0			2446	2160	1967	1246	836	760	51.0	38.1	38.7	409	315	[illegible]	210	[illegible]	163	66.1	69.3

Solids					Dissolved Oxygen			Free NH_3			Nitrites		Nitrates			pH			Temperature		
ile		% Volatile																			
	G	I	R	G	I	R	G	I	R	G	R	G	I	R	G	I	R	G	Influent	Effluent	Room
m	ppm	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm				°C	°C	°C
					0	0.5	0									6.9	8.4	8.4	23.5	23	24
					0	3.4	1.1									7.1	8.1	8.0	23	23.6	24
																7.2	8.1	8.0	23		23
						2.5	2.5									7.2	8.4	8.0	23	22	27
6	76	76.6	63.2	66.1				3.7	3.3	4.5			1.5	9	6						
7	[illegible]	65.5	63.2	65.5				[illegible]	[illegible]	5.0			1.4	1.8	9						
					0	2.5	2.1	4.4	5.0	6.0				8	6	7.0	8.0	8.0	23.5		24
					0	0	0	6.7	8.0	16.0	0.2	0.14				7.1	8.1	8.0	23.5		24
								2.5	2.0	7.5						[illegible]	[illegible]	[illegible]	22.5		26
					0	0.5	0.85	3.0	4.5	20.0						7.1	8.1	7.1	23	22.5	27
					0	0.85	0									7.2	8.1	7.7			[illegible]
					0	0.2	0.5									6.8	8.2	7.5	26		29
					0	0	0									7.1	8.1	8.4	25	25	27
0	[illegible]	66.5	65.1	66.1				7	[illegible]	8			3.7	10	6						
1	[illegible]	68.8	66.2	66.2	0	0	0.4						1.6	1.2	1.0		8.4	8.1	23		23
						2.5	2.7	[illegible]	1.7	2.5	0.7	0.25	[illegible]	2.0	1.0		8.1	[illegible]	23	23	[illegible]
					0	3.35	1.4	1.5	3.7	2.3	0.13	3.5	1.5	3.5	3.0	7.3	8.1	7.8	23	21	23
					0	0.1	0		3.9	10									22.5		22
					0	0		1.0	3.3	5.8						6.2	8.1	7.9	23		22
						0	0	12.5	7.2	4.0	0.7	0.9	4.0	7.0	1.4		8.0	7.7	25	25.5	26
						0	0	3.5	24.0	35.0	0.7	0.7					8.0	7.7	23	25	25
5	268	63.4	59.1	68.2				4.2	6.0	6.0	0.7	1.0	0.4	2.6	5.0						
7	273	64.5	64.9	64.7													8.0	7.9	23.5	23.0	22
						0	0									6.2	8.1	8.0	23.5	23.5	22
						4.1	3.6									6.5	8.1	8.1	23.6	23.6	23
						0.2	0									[illegible]	8.1	8.4			
						0	0									6.3	8.0	8.1	23	21	24
						0	0.55										8.0	8.0	23	21	22.6
						1.35	0.5										8.1	8.1		21.5	21
						0	0										8.1	8.2	24	23	27
[illegible]	163	66.1	60.3	56.6				[illegible]	[illegible]	3.3			15	7.0	6.5						
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		0	0	8.6	[illegible]	[illegible]			6.0	8.0	[illegible]		8.0	8.0	23	24	24

pH		Temperature			Sloughing		Clogging		Notes:
R	G	Influent °C	Effluent °C	Room °C	R	G	R %	G %	
									Feeder belt broken for 8 hrs. No sample take
8.4	8.4	23.5	23	24	+	+			" " " " 1 hr. Cloudy Eff.
8.1	8.0	23	23.0	24.4					Tripper drive belt broken 6 hrs.
8.1	8.0	23		23.5	+	+			
8.4	8.1	23	22	21					Very heavy Inf.
8.0	8.0	23.5		24.5					
8.1	8.0	23.5		24	++	++			
8.3	8.2	22.5		26	++	++			
8.1	7.7	23	27.0	27	++	++			Tripper drive stuck several hrs.
8.1	7.7			21					" " " " . Thus con
8.2	7.8	26		29	++	++			Both drive belts broken— solder from t
8.5	8.4	20	20	21	+++	+++			Very dark Inf.
8.4	8.1	23		23	+	+		20	Roof [illegible] noted [illegible] several [illegible]
8.1	7.9	23	22	21	+	+		50	
8.1	7.8	23	21	20	++	N		50+	Liquid runs of sampling tubes on sides
		22.5		22					
8.1	7.9	23		22				75	Decided change in appearance of G. Eff.
8.0	7.7	25	25.5	26	+++	++	+	60	
8.0	7.7	23	25	25	+	+	10	60	
8.0	7.9	23.5	23.0	22	+++	+++	20	90	Very cloudy Eff.
8.1	8.0	23.5	23.5	24.4			10	10	
8.1	8.1	23.6	23.0	23.0	+	+	0	0	Filter media almost bare from film. (
8.1	7.7								Main drive belt ("V" belt) slipped — tight beari
8.0	8.1	23	21	24	+	+	0	0	Very dusty sheep manure.
8.0	8.0	23	21	22.5	+	+	+	0	
8.1	8.1		21.5	21	N	N	50	0	
8.1	8.2	24	23	27			50	0	
8.0	8.1	23	24	24	+		50	16	

es:
elt broken for 8 hrs. No sample taken.
" " " 1 hr. Cloudy Eff.
drive belt broken 6 hrs.
heavy Inf.
r drive stuck several hrs.
" " " " . Thus composite sample used.
drive belts broken — Solder from tank above.
dark Inf.
alligan noted ponding several days earlier.
ranoff of sampling tubes on sides of filter indicating marked clogging.
a change in appearance of G. Eff.
cloudy Eff.
...ain almost gone from filter. G especially.
rive belt ("V" belt) slipped — Tight bearing
dusty sheep Manure.

5	G	94	49	6120	359	700	32	76	95.4	89.1	1200	268	300	77.7	75.0	30	11	
6	G	95	33	6122	362	690	35	140+	94.9		1210	284	340	76.5	71.9	75	21	
7	G	96	71.5	6090	360	790	42	65	94.7	91.8	1000	280	304	72.0	69.6	97	11	
8	G	97a	41	6213		810	34	112	96.8	86.2	1270	284	322	77.6	74.6	80	21	
8	WC	97b									970	270	296	70.1	69.5			2262
9	G	98	34	6004		650	47	98	92.8	84.9	1410	274	316	81.4	78.5	94	21	2256
10	G	99	22	6070		670	37	94	94.2	85.9	1190	241	280	78.2	75.2	21	21	
11	G	100	40	5310		570	18	13	96.8	97.7	1000	168	200	83.2	80.0	100	100	
11	C	101				925	18	27	96.6	94.9	660	236	237	67.2	66.0	98	50	
12	G	102	36	6045		820	55	49	93.3	94.0	1160	262	296	76.4	75.3	21	21	
13	G	103	30	6020		670	65	38	90.3	94.3	1120	274	268	75.5	76.1	21	21	
14	G	104	36	6020		750	42	41	94.4	94.5	1060	262	264	75.3	75.1	21	21	2370
15	G	105	35	6030		740	45	49	93.9	93.4	630	286	260	54.6	58.7	21	21	2481
15	WC	106				585	60	109	89.1	87.9	410	262	260	44.4	40.0			2476
16	G	107	33	6070	356	650	58	64	91.1	90.2	1360	290	276	78.7	79.9	21	21	2547
17	G	108	36	6082	354	1050	76	103	92.8	90.2	1170	254	252	75.7	75.9	21	21	
18	C	109	34		362	700	33	34	95.3	95.1	980	236	260	76.9	73.5	90	37	
19	G	110	33	6036	353	370	14	30	96.2	91.9	610	150	160	75.4	73.8	100	21	
20	G	111	35	6008		540	73	108	86.5	80.0	1080	280	278	74.1	74.3	21	21	
21	G	112	[illegible]	[illegible]		620	68	115	89.7	82.6	1130	262	264	76.8	76.6	37	21	
22	G	113	41	6110		630	65	134	90.0	79.1	1220	292	316	76.1	74.1	21	21	
23	G	114	36	6080		720	126	109	82.5	80.7	1260	328	334	74.0	73.5	21	21	
24	G	115	34	6130	357	710	56	123	92.1	82.7	1060	282	310	73.4	70.6	60	5	
24	WC	115b									1000	268	262	70.4	70.9			2496
25	G	116	193	6100	360	770	77	118	90.8	84.7	1020	278	280	75.1	72.5	50	21	2548
26	G	117	35	6090	353	990	83	131	91.6	86.2	1000	242	274	77.0	76.2	37	21	
27	C	118	[illegible]	6020		[illegible]	[illegible]	[illegible]	[illegible]	90.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21	
28	C	119	24	5800	300		38	105				234	241			30	3	
29	G	120	24			1100	91	155	92.1	86.5	1200	218	242	81.8	79.8	21	21	
30	C	121	13	5780	354	760	66	103	91.3	86.4	1000	246	248	76.0	75.1		4	
31	G	122a	38	6026	350	1030	128	321+	87.5	69-	1200	274	492	75.5	59.0	21	0	
31	WC	122c									800	240	260	70.0	61.5			2143
Sept 1	G	123	135	6036	360	1160	147	320	87.3	72.4	1170	294	484	74.9	58.5	21	0	2091
2	G	124	65	6050		1240	240	305	80.6	75.1	1260	464	488	69.2	61.3	21	0	
3	G	125	15	6030		980	121	312	87.6	68.1	1020	380	484	62.7	52.5	21	0	
4	G	126	36	6070		1330	104	304	92.2	77.1	1340	412	488	67.2	63.7	21	0	
5	G	127	34	6024	358	650	62	108	89.7	82.0	960	292	320	69.2	64.7	60	2	
6	WC	127b									1120	472	428	57.9	61.8			2795
6	G	128	0	6035	360	880	90	230	89.8	73.8	1060	392	368	63.0	65.3	5	0	2816
7	C	129	48	5990	360	660	52	100	92.1	85.0	1200	336	420	60.4	52.9	7	1	
8	G	130	36	6050		930	132	240	85.8	74.2	1240	416	466	66.4	62.4	5	1	
9	G	131	36	6320	361	1230	222	420	82.0	65.8	1200	470	544	63.3	54.7	11	0	
10	G	132	34	5760	360	1080	148	206	87.2	75.2	1160	442	492	61.4	57.6	15	0	

85.7	82.0	100	75																		
77.7	75.0	30	11																		
75.5	71.9	75	21																		
72.0	69.6	97	11																		
77.6	74.6	80	21																		
72.1	69.5			2262	1580	1921	1176	580	508	52.0	36.7	29.0	438	685	393	278	405	268	63.4	59.1	
81.4	78.5	94	21	2258	1683	1707	1065	664	711	47.2	37.5	37.4	678	550	422	480	357	273	64.5	67.9	
78.2	75.2	21	21																		
83.2	80.0	100	100																		
61.6	61.5	78	60																		
76.4	73.3	21	21																		
75.5	76.1	21	21																		
75.3	70.1	21	21	2570	1972	1863															
59.6	58.1	21	21	2481	1814	1880		674			37.4										
77.2	45.0			2776	2160	1767	1246	580	760	51.9	38.1	38.7	409	316	248	270	232	163	66.1	60.3	
78.7	79.9	21	21	2547		1853	1327		764	52.1		41.[illegible]	480	390	268	331	191	153	69.0	49.8	
75.7	75.9	21	21																		
76.9	73.5	90	37																		
75.4	73.8	150	21																		
74.1	74.3	21	21																		
76.8	76.6	37	21																		
76.1	74.1	21	21																		
74.0	73.5	21	21																		
73.1	70.6	60	5																		
70.4	73.4			2776	1846	1807	1312	861	742	52.6	44.7	40.0	578	470	[illegible]	241	288	76	65.8	61.3	
75.7	72.5	50	21	2548	1833	1812	1363	800	737	53.5	44.2	40.7	580	438	150	345	254	84	59.6	58.0	[illegible]
77.0	76.2	[illegible]	21																		
63.6	62.6	37	21																		
		30	3																		
81.8	79.3	21	21																		
76.6	76.1	21	4																		
76.5	59.9	21	0																		
72.6	61.5			2143	1615	1645	1242	665	756	58.0	41.2	42.9	491	335	277	333	237	275	67.8	70.8	7
74.7	58.6	21	0	2091	1370	1652	1131	520	733	54.0	38.0	44.4	477	331	353	329	233	280	68.7	70.4	6
63.2	61.3	21	0																		
62.7	52.5	21	0																		
67.2	63.7	21	0																		
69.2	64.7	50	2																		
77.9	62.8			2795	2126	2156	1570	984	746	56.2	46.3	43.9	478	386	236	329	257	156	68.6	65.8	6
63.0	65.3	5	0	2516	2112	2103	1532	994	768	55.1	44.7	50.8	570	492	343	350	266	184	68.6	70.8	5
60.7	52.9	7	1																		
66.1	62.4	5	1																		

						0	0.1	0		3.0	10										22.5	
							0	0	1.0	3.3	5.8							6.2	8.1	7.9	23	
							0	0	12.5	3.2	4.0	0.7	0.9	4.0	9.0	1.4			8.0	7.7	25	25.5
							0	0	3.5	20.0	35.0	0.7	0.7						8.0	7.7	23	25
8	40.5	26.8	63.4	59.1	68.2				4.2	6.0	5.0	0.7	1.0	0.4	2.0	5.0						
7	35.7	27.5	64.5	64.9	64.7														8.0	7.9	23.5	23.0
							0	0										6.2	8.1	8.0	23.5	23.5
							4.1	3.6										6.5	8.1	8.1	23.5	20.0
							0.2	0										6.2	8.1	8.1		
							0	0										6.3	8.0	8.1	23	21
							0	0.33											8.0	8.0	23	21
							1.35	0.5											8.1	8.1		21.5
							0	0											8.1	8.2	24	23
	22.6	14.3	66.1	69.3	56.6				8.0	2.0	3.5			15	7.0	6.5						
	14.5	15.3	67.0	57.8	55.2		0	0	8.0	20	3.5			6.0	6.0	6.0			8.0	8.1	23	24
							Trace	0										6.0	8.0	8.0	24.5	24
																		6.7	8.0	8.1	24.5	
							2.25	1.90											8.0	7.9	21	19.5
							2.0	1.65											8.0	8.0	22	21
							1.0	0.33											8.0	8.0		
							0	0											8.0	7.9	22.5	21.5
							0	0											7.9	8.0	23.5	23
							0	0				0.5	0.16						7.9	7.9	24	24
	28.5	7.5	62.8	61.3	47.0				5	[illegible]	5	2.5	0.7		12.5	1.2						
	22.7	7.4	79.6	58.0	60.0		1.30	0	7.5	[illegible]	7				16.5	1.5					23	21
							3.55	0.25										6.2	7.9	7.9	21	20
							0.25	0										6.5	7.9	8.0		
							2.4	0														
							1.5	0										6.2	7.9	7.8	22.5	21
							0	0										6.2	7.9	8.6	22	
							0	0										6.0	8.0	7.5	19	19
	23.7	21.3	67.8	70.8	76.9				0.5	7	5.5			3.5	5	1.9						
	23.5	28.5	68.7	70.4	80.8				5.5	25	5			2.5	9	1.2		6.1	7.9	7.5	19	20
																		6.0	7.9	7.3	21	22
																			7.9	7.0		
							0.10	0											8.0	7.8	20	20
							0.10	0										6.3	[illegible]	7.8	23	23
	26.7	15.6	68.6	65.8	66.1				12	25	6.0			7.5	8.5	9.0						
	26.6	18.7	68.6	70.8	58.6		Tr	0	13	8.5	6.0			8.6	9.5	9.0			7.9	7.7	24	25
							0	0											8.0	8.1		
							0	0											7.9	7.7	25	25
							0	0										6.0	7.9	7.8		25
							Tr	0											7.8	7.6	24.1	25.5

1.3	8.1	7.8	23	21	20	N	N		50+	Liquid ran out of sampling tubes on stage
			22.5		22					
6.2	8.1	7.9	23		22				75	Decided change in appearance of G. Eff
	8.0	7.7	25	25.5	26	+++	++	+	60	
	8.0	7.7	23	25	25	+	+	10	60	
	8.0	7.9	23.5	30	22	+++	+++	20	90	Very cloudy Eff.
6.2	8.1	8.0	23.5	23.5	24.5			10-	10-	
6.5	8.1	8.1	23.6	23.0	23.5	++	+	0	0	Filter media almost bare from film.
[illegible]	8.1	8.1								Main drive belt ("V" belt) slipped: — Tight[illegible]
6.3	8.0	8.1	23	21	24	+	+	0	0	Very dusty sheep manure.
	8.0	8.0	23	21	22.5	?	+	+	0	
	8.1	8.1		21.5	21	N	N	50	0	
	8.1	8.2	24	23	24			50	0	
	8.0	8.1	23	24	24			50	75	
6.0	8.0	8.0	24.5	24	25	+	N	+	+	
[illegible]	8.0	8.1	22		23.5	+		33	75	Feeder belt broken:— Composite samp
	8.0	7.9	21	19.5	21	++	—	90	90	Clear Eff.
	8.0	8.0	22	21	22	+++	+++	+	50	Very cloudy Eff.
	8.0	8.0						0	0	
	8.0	7.9	22.5	21.5	20	+++	+++	0	0	
	7.8	8.0	23.5	22.5	23			0	0	Tipping tray stuck. Cloudy Eff.
	7.7	7.9	21	21.5	20	++	+	0	—	
			23	21	20	N	N	0	0	
[illegible]	7.9	7.9	21	20	20			0	0	
	7.7	8.0								Feeder clogged:— wool in sheep manu
					23			+	+	" ran empty: Composite sa
2	7.9	7.8	21.5	21	22.5	N	N	+	+	" chain caught.
2	7.9	8.0	22		19.5	N	N	+	+	" clogged:— wool in sheep manu
0	8.0	7.5	19	19	19	N		0	100	Very dark Eff-G.
1	7.9	7.5	19	20	20	++	+	0	100	Very dark Eff.— G more cloudy
0	7.9	7.5	21	22	24	++	++	0	100	
	7.7	7.5			26			0	50	Rock on G completely bare. Feeder brid
	8.0	7.8	25	25	24	+++	+++	0	0	Cloudy Eff. from G.
0	7.9	7.8	25	25	24	+++	N	0	0	
	7.9	7.7	24	25	25	+++	+	0	0	Very dark Eff. Very light sheep manure.
	8.0	8.1			23.5			0	0	Block of wood caused mixer to stop.
	7.9	7.7	23	25	27	+++	+	50	0	Very cloudy Eff. from G
0	7.7	7.8		25	25	++	+	50	10	" " " " both

change in appearance of G. Eff.

dy Eff.

ids almost bare from film. G especially.
e belt (½" belt) slipped; - tight bearing
sty sheep Manure.

belt broken. Composite sample dead.
Eff.
oudy Eff.

Tray stuck. Cloudy Eff.

Clogged - wool in sheep manure.
ran empty. I composite sampler stuck.
rain caught.
logged - wool in sheep manure.
rk Eff. G.

rk Eff. - G more cloudy.

completely bare. Feeder bridged. Screen belt removed.
Eff. from G.

k Eff. Very light sheep Manure - much straw.
f wood caused mixer to stop.
dy Eff. from G
both

8 ω1 Sheep Manure-Milk Powder Mixture

24	G	115a	34	6130	357	710	55	123	92.1	82.7	1060	282	310	73.4	70.6	60	5
24	WC	115b									900	248	262	70.4	70.9		
25	G	116	135	6100	360	770	71	118	90.8	84.7	1020	248	280	75.7	72.5	50	21
26	G	117	36	6090	353	990	83	137	91.6	86.2	1130	242	274	79.0	76.2	37	21
27	C	118	24	6046		680	34	62	95	90.9	650	222	228	63.6	62.6	37	21
28	C	119	24	5800	350		38	105				234	267			30	3
29	G	120	24			1150	91	155	92.1	86.5	1200	218	242	81.8	79.8	21	21
30	C	121	13	5980	354	760	66	103	91.3	86.4	1050	246	248	76.6	75.4	21	4
31	G	122a	38	6026	350	1030	128	320	87.5	69-	1200	274	442	75.5	59.0	21	0
31	WC	122b									800	242	260	70.0	67.5		
Sept 1	G	123	132	6036	360	1160	147	320	81.3	72.4	1170	294	484	74.7	58.6	21	0
2	G	124	65	6050		1240	249	308	80.6	75.1	1260	464	488	63.2	61.3	21	0
3	C	125	75	6030		980	121	312	87.6	68.1	1020	350	484	62.7	52.5	21	0
4	G	126	36	6012		1330	134	304	92.2	77.1	1340	440	488	67.2	63.7	21	0
5	G	127	34	6024	358	600	62	108	89.7	82.0	920	296	320	69.2	64.7	60	2
6	WC	[illegible]									1150	372	328	57.2	[illegible]		
6	G	128	0	6035	360	880	90	230	89.8	73.8	1060	392	368	63.0	62.3	5	0
7	C	129	48	5970	360	660	52	100	92.1	85.0	1250	336	400	60.4	52.9	7	1
8	G	130	36	6050		930	132	240	85.8	74.2	1240	416	466	66.4	62.4	5	1
9	G	131	36	6320	361	1250	222	420	82.0	[illegible]	1200	472	[illegible]	63.2	54.7	11	0
10	G	132	24	5764	360	1090	166	405	84.6	62.8	1150	478	472	61.7	61.6	15	0
11	G	133	36	6030	365	830	114	315	86.3	62	1030	292	420	71.1	59.2	21	1
12	C	134	25	6030	363	1000	122	355	87.8	64.5	870	272	[illegible]	69.5	48.8	37	1
12	WC	134b									840	384	312	58.3	53.4		
13	G	135	42	6053	362	1604	315	590+			1620	690	752	61.0	57.4	1	0
14	G	136	145	5980		1125	225	470	80.0	59.2	1120	425	504	62.1	55.1	1	1
15	G	137	49	5950		970	188	355	80.6	63.4	1210	468	536	61.3	63.6	21	0
16	G	138	36	6015		1200	[illegible]	580	85.2	54.5	1290	436	588	66.2	54.4	21	0
17	G	139	41	6020		1220	236	470	80.6	61.4	1250	484	560	61.3	55.1	15	0
18	G	140	39			790	150	530	81.0	33.3	1140	416	520	63.5	59.4	5	0
19	G	141	26	6030	360	1140	300	4.5	73.6	71.8	1410	512	584	65.7	[illegible]	15	0
20	G	142	29.5	6000		815	98	148	88	81.8	970	242	408	69.9	57.8	37	37
21	G	143	34	6080		705	662	644	.2	5.1	1330	756	768	53.0	53.0	0	0
24	G	146				620	310	240	50.5	62.4	980	436	440	55.5	53.1	1	1
28		148															

3.4	70.6	60	5																		
0.4	70.9			2496	1846	1809	1312	861	742	52.6	46.1	42.0	518	412	132	241	280	76	68.8	61.3	47
5.7	72.5	50	21	2548	1833	1812	1363	860	737	53.5	[illegible]	40.7	580	438	150	549	257	84	59.6	58.0	66
7.0	76.2	57	21																		
[illegible]	[illegible]	57	21																		
		30	3																		
1.8	79.3	21	21																		
[illegible]	[illegible]	21	4																		
5.5	57.0	21	0																		
[illegible]	[illegible]		7	2143	1615	1645	1242	665	702	58.0	41.2	42.9	491	335	277	333	237	213	67.5	70.8	76
4.9	58.6	21	0	2091	1370	1652	1131	520	733	54.0	38.0	44.4	477	551	353	329	253	280	68.7	70.4	80
3.2	61.3	21	0																		
2.7	52.5	21	0																		
7.2	63.7	21	0																		
7.2	64.7	50	[illegible]																		
7.9	64.8			2795	2126	2056	1070	981	996	56.2	46.3	43.9	478	386	256	329	257	156	68.6	65.8	61
3.0	65.3	5	0	2816	2112	2103	1332	994	1069	55.1	44.1	50.8	570	402	343	351	266	184	68.6	70.8	58
20.7	52.9	7	1																		
56.7	62.4	0	1																		
3.3	54.7	11	0																		
3.7	57.6	15	0																		
11.7	57.2	21	1																		
59.5	48.8	37	1																		
59.3	53.4		1	2396	2146	2061	1099	866	810	45.8	40.4	39.3	444	345	400	308	365	264	69.4	67.0	6
61.0	57.1	1	0	2550	2169	2120	1262	867	850	49.5	40.0	40.1	480	399	417	332	402	279	69.2	67.1	6
2.1	53.7	1	1																		
21.3	53.6	21	0																		
56.2	57.4	21	0																		
1.3	55.1	15	0																		
63.5	27.7	5	0																		
3.7	58.6	15	0																		
7.9	57.8	37	37																		
30	33.0	0	0																		
5.5	53.1	1	1																		

						0	0				0.5	0.16					7.9	7.9	24	24.5	25
8	76	63.8	61.3	49.0				3	3	5	0.3	0.9		12.5	7.2						
7	84	57.6	58.0	66.0		1.35	0	2.5	0	1				16.[illegible]	11.5				20	21	20
						3.55	0.25									6.5	7.9	7.9	21	20	20
						0.25	0									6.5	7.9	8.0			
						2.4	0														23
						1.5	0									6.2	7.9	7.8	22.5	21	22
						0	0									6.2	7.9	8.0	22		19.5
						0	0									6.0	8.0	7.5	19	19	19
7	[illegible]	67.8	70.8	76.9				6.5	9	5.5			3.5	6.5	[illegible]						
3	285	68.7	70.4	80.8				3.5	2.5	5			3.5	6	11.2	6.1	7.9	7.5	19	20	20
																6.0	7.9	7.5	21	22	24
																	7.8	7.5			26
						0.6	0										8.0	7.8	25	25	24
						1.25	0									6.3	7.9	7.8	25	25	24
[illegible]	156	68.6	66.8	66.1				1.2	8.5	6.5			7.5	8.0	9.2						
[illegible]	184	68.6	70.8	58.6		Tr	0	1.3	8.5	6.2			8.5	7.5	9.0		7.7	7.7	27	25	23
						0	0										8.0	8.1			25
						0	0										7.9	7.7	23	25	27
						0	0									6.3	7.9	7.8		25	26
						Tr	0										7.7	7.6	24.7	25.3	25.2
						0	0										7.9	7.9	23.5	25.0	24.2
						0.6	0														20.1
[illegible]	264	69.4	67.0	66.0				28	45	35			1.0	5.0	1.4	7.0	8.1	8.0			
2	279	69.2	67.1	66.8		0	0	35	95	40			3.0	6.0	1.8	6.1	7.7	7.4	21.8	19	17
						0	0	10	50	100						6.0	7.7	7.5	23.2	18.4	17.5
						0	0	5	12	9							7.9	7.7	22.6	21.6	18
						0	0										7.9	7.5	24.0	21.4	20
						Tr	0										7.8	7.6	23.5	20.6	19.5
						0	0										7.9	7.5	24.0	21	21.4
						0	0										7.8	7.6	23.0	23.2	22
						1.3	0										7.9	7.9	19.0	17.2	15
																6.0	6.2	6.4	20.5	19.6	19.2
																6.3	6.5	6.7	20	19.2	21
																6.0	6.5	6.0			

7.9	24	24.5	25	++	+	0	0	
	20	21	20	N	N	0	0	
7.9	21	20	20			0	0	
8.0								Feeder clogged - wool in sheep manure
			23			+	+	" ran empty. Composite sampler
7.8	22.0	21	22.5	N	N	+	+	" chain caught.
7.6	22		19.0	N	N	+	+	" " clogged - wool in sheep manure.
7.5	17	18	19	N		0	100	Very dark Eff. G
7.5	19	20	20	++	++	0	100	Very dark Eff. G more cloudy
7.5	21	22	24	++	++	0	100	
7.6			26			0	50	Rock on G completely bare. Feeder bridged. S
7.8	25	25	24	+++	+++	0	0	Cloudy Eff. from G
7.8	25	25	24	+++	N	0	0	
7.7	27	27	25	+++	+	0	0	Very dark Eff. Very light Sheep Manure much
8.1			23.5			0	0	Block of wood caused mixer to stop.
7.7	26	25	27	+++	+	30	0	Very cloudy Eff. from G
7.8		25	25	++	+	50	10	" " " " both
7.6	21.7	25.3	25.3	++	+	20	0	" " " " G
7.9	23.5	25.0	24.2	++	++	10	0	
			20.8	+	+	0	0	
8.0								
7.4	21.8	19	17	+++	+++	0	0	Very heavy Inf & Eff. Coarse, granular sh.
7.5	23.2	18.4	17.5	+++	++	0	0	" " " "
7.7	22.6	21.6	18	++	+++	0	0	
7.5	24.0	21.4	20	+	+++	0	0	Very cloudy G
7.6	23.5	20.6	19.5	++	++	0	0	" "
7.5	24.0	21	21.4	+	+++	0	0	
7.6	23.0	23.2	22	++	++	0	0	Traveling Screen Replaced.
7.9	14.0	17.2	15	N	N			Bridging in Feeder due to balls of wool
6.4	20.5	18.6	19.2	+++	+++	Tr	Tr	Metal Cones placed on bottom of Filters. Air
6.7	20	19.2	21	+++	++	30	10	Flies and odor increasing
6.0				+++	++	50	10	Experimental Run Concluded at Noon.

er clogged:- wool in sheep manure.
ran empty. Composite sampler stuck
chain caught.
clogged:- wool in sheep manure.
dark Eff. G.

dark Eff. G more cloudy

n G completely bare. Feeder bridged: Screen belt removed.
dy Eff. from G.

dark Eff. Very light Sheep Manure - mixing tank.
of wood caused mixer to stop.
loudy Eff. from G.
" " " both
" " " G

eary Inf & Eff. Coarse granular sheep manure.
" "

Cloudy G

eling Screen replaced.
gging in Feeder due to balls of wool in manure
Cones placed on bottom of Filters. Air thus shut off
s and odor increasing
rimental Run Concluded at Noon.

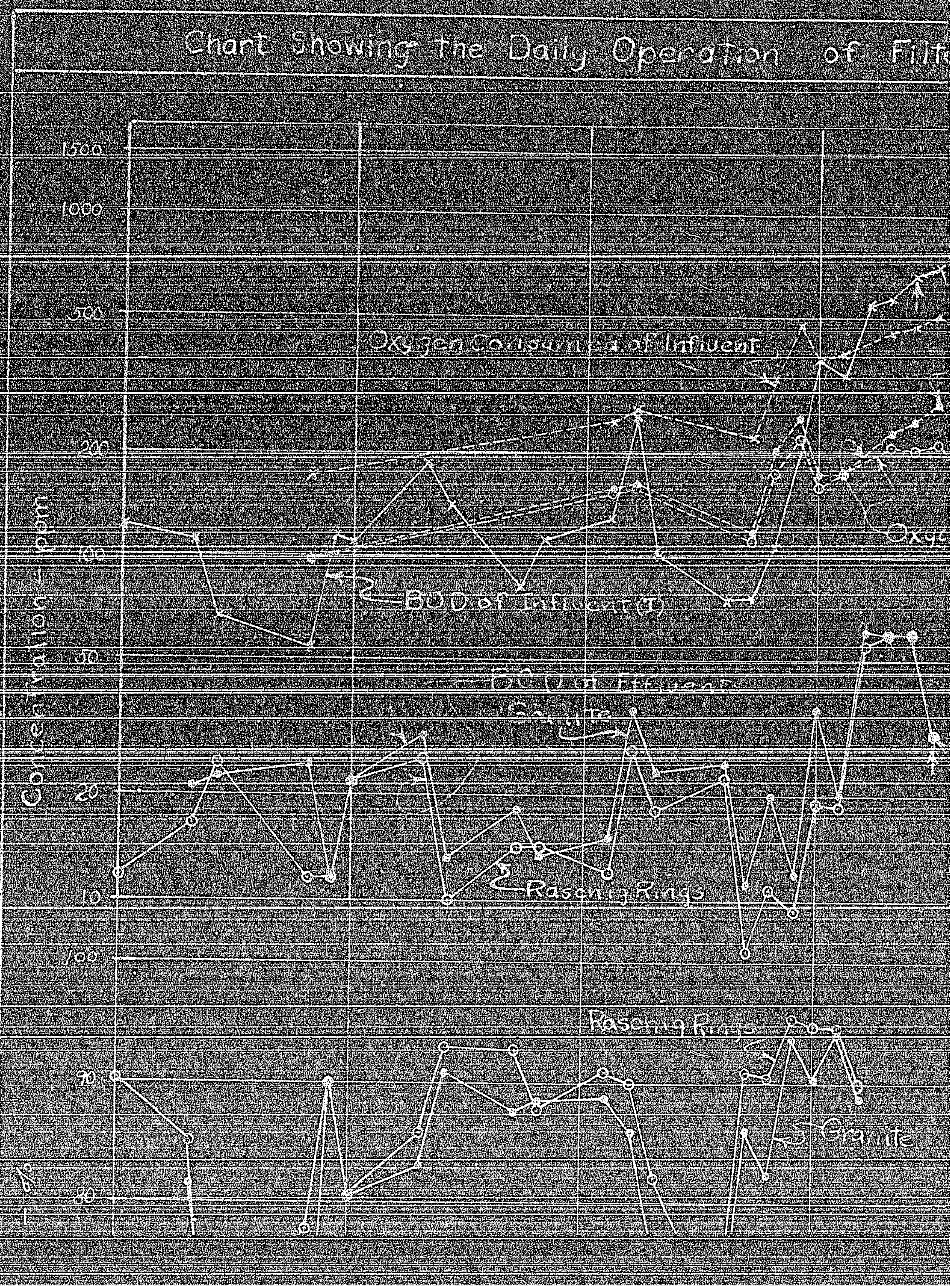
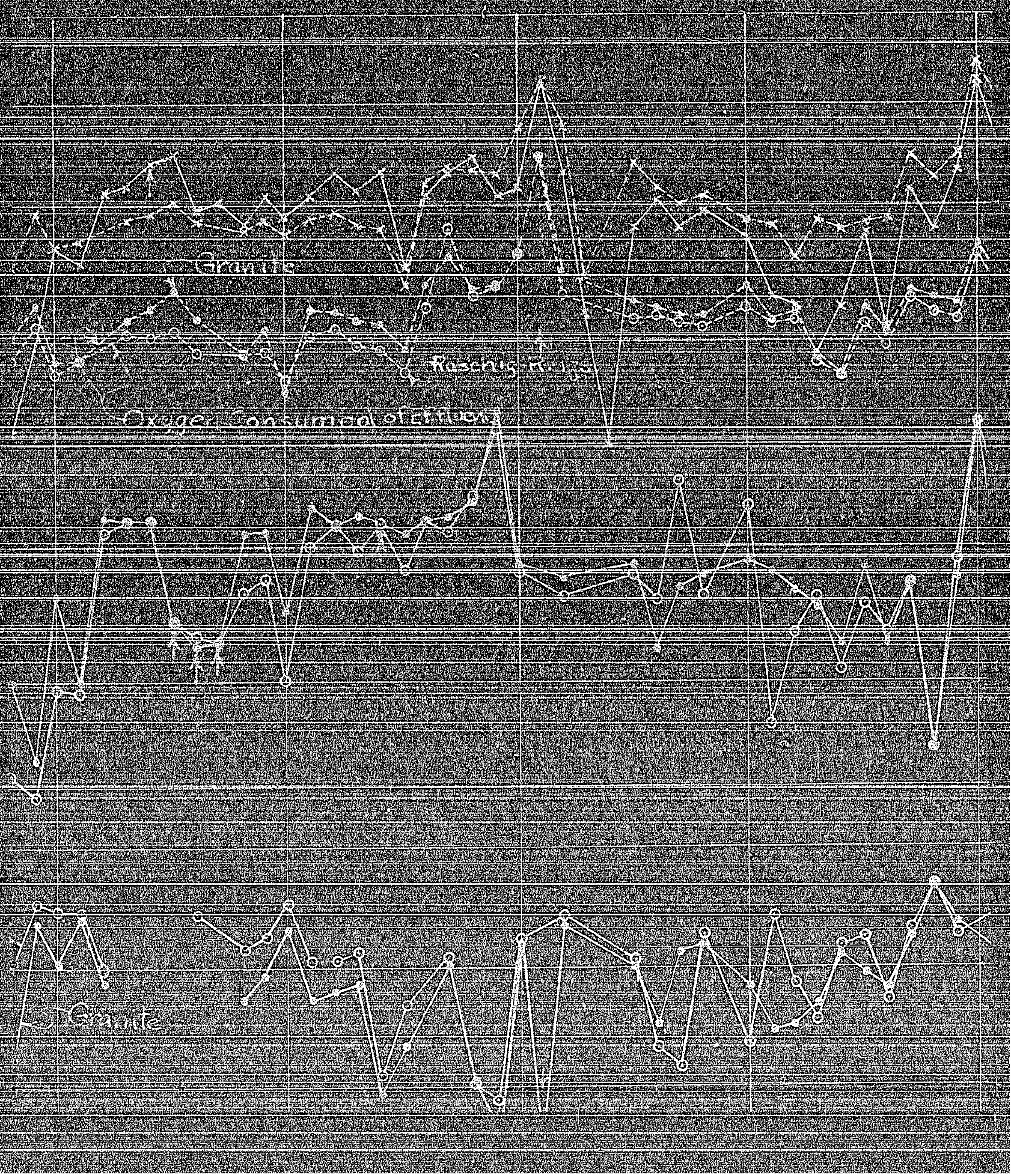


Chart Showing the Daily Operation of Filt
1500
1000
500
Oxygen Consumed of Influent
200
100
BOD of Influent (I)
Oxyg
50
BOD of Effluent
20
10
Raschig Rings
100
Raschig Rings
90
Granite
80
Concentration - ppm
%

of Filters.



Granite
Raschig Rings
Oxygen Consumed of Effluent
Granite

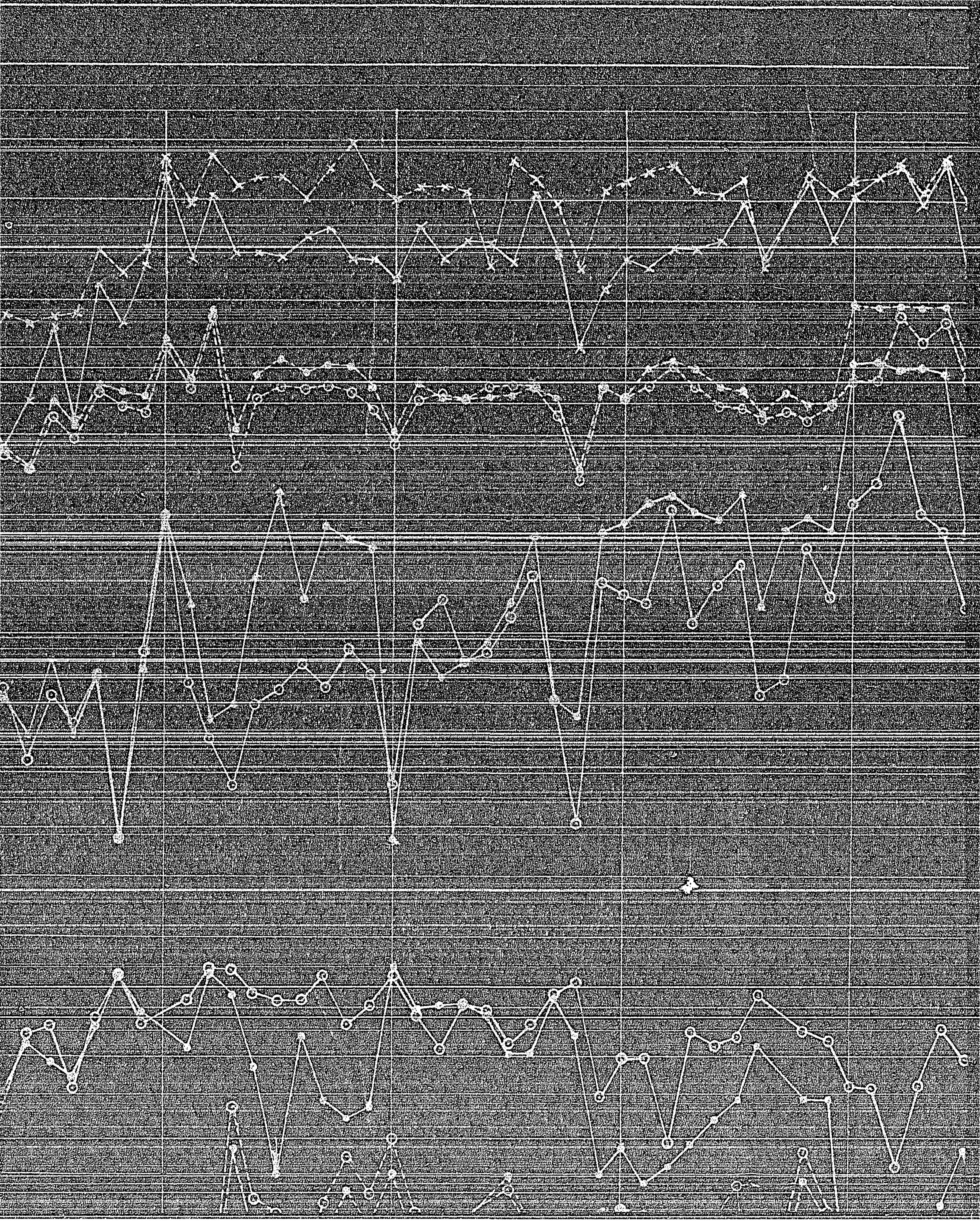


Fig. 2, p. 34

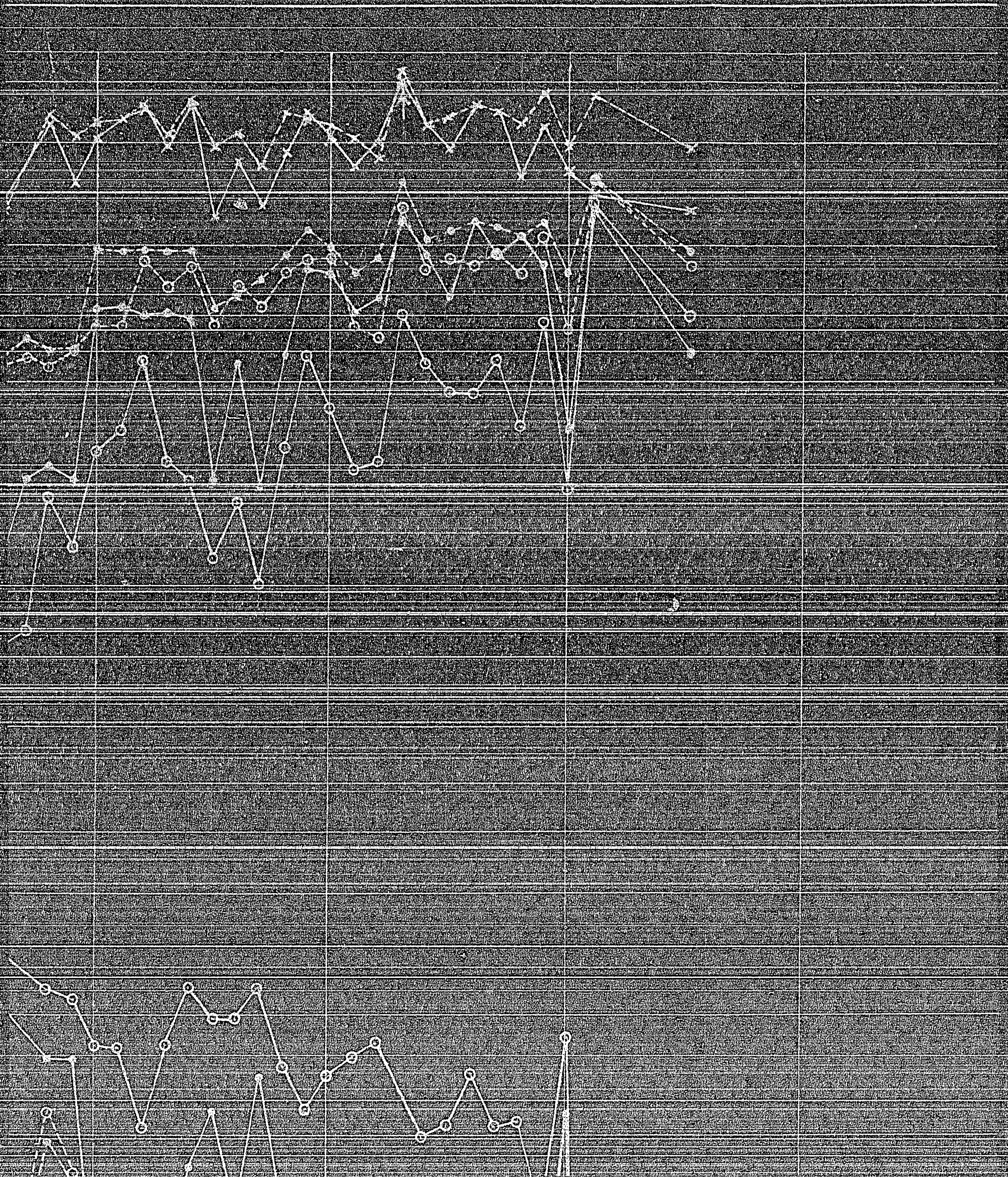
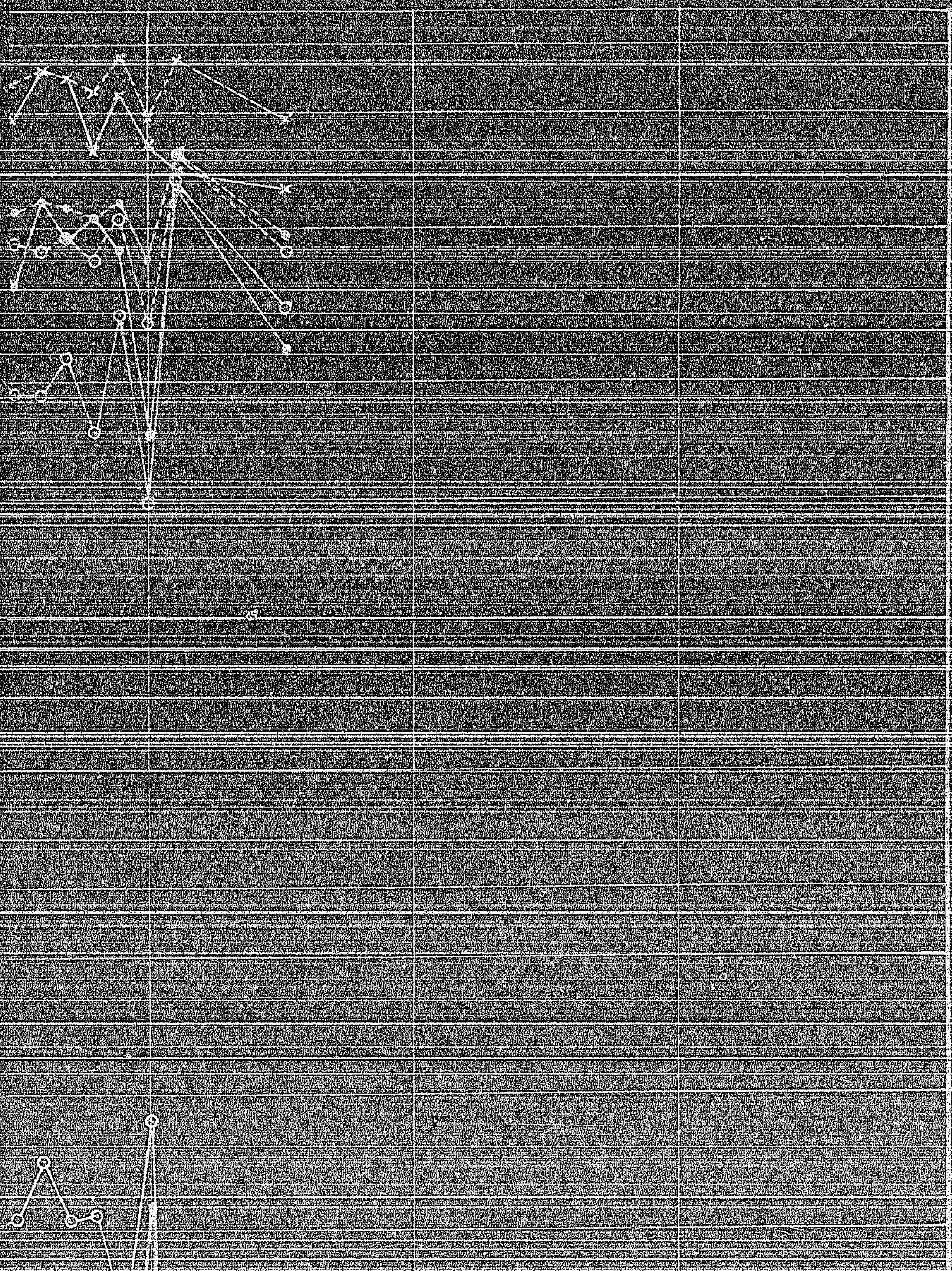
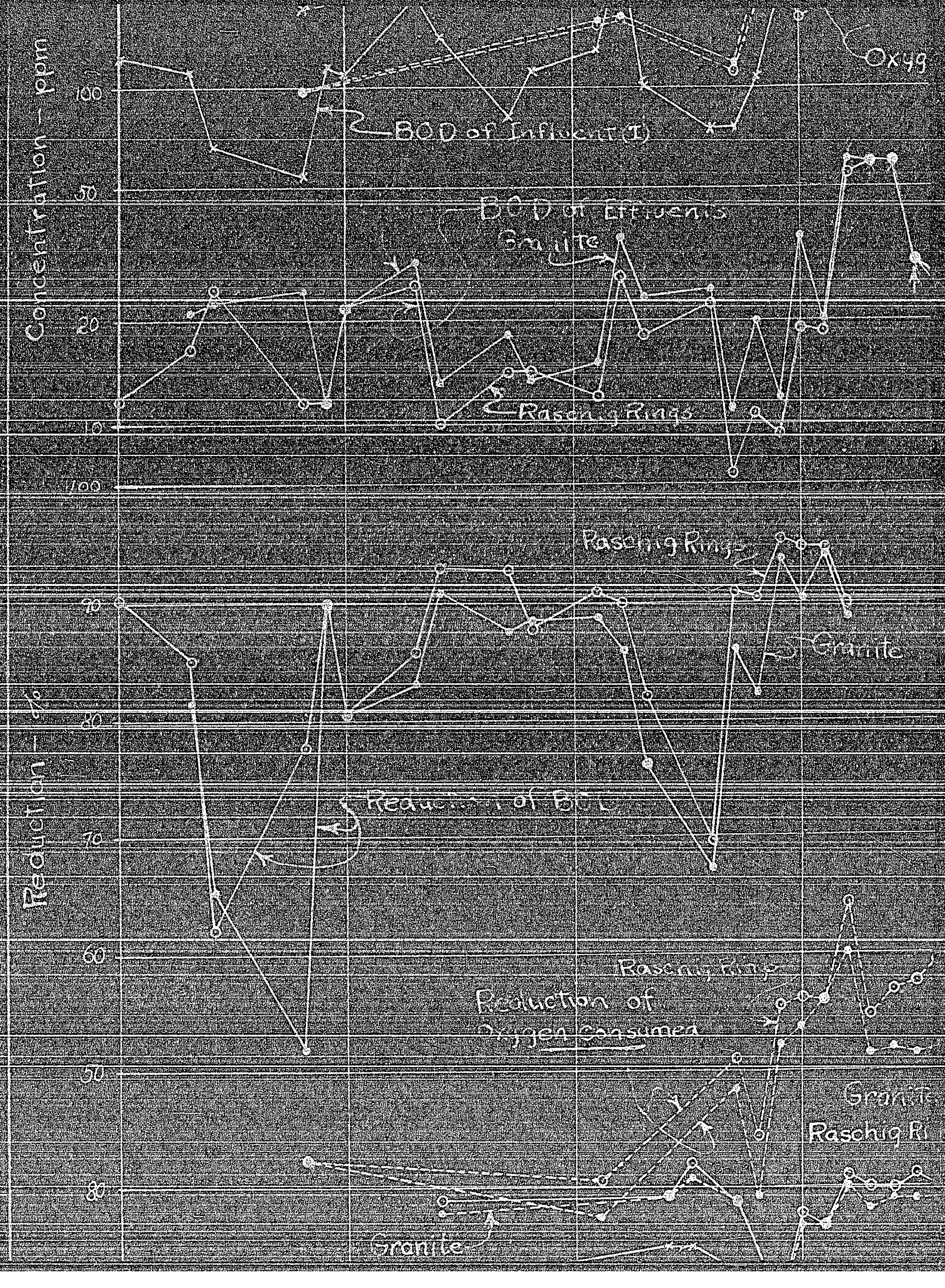
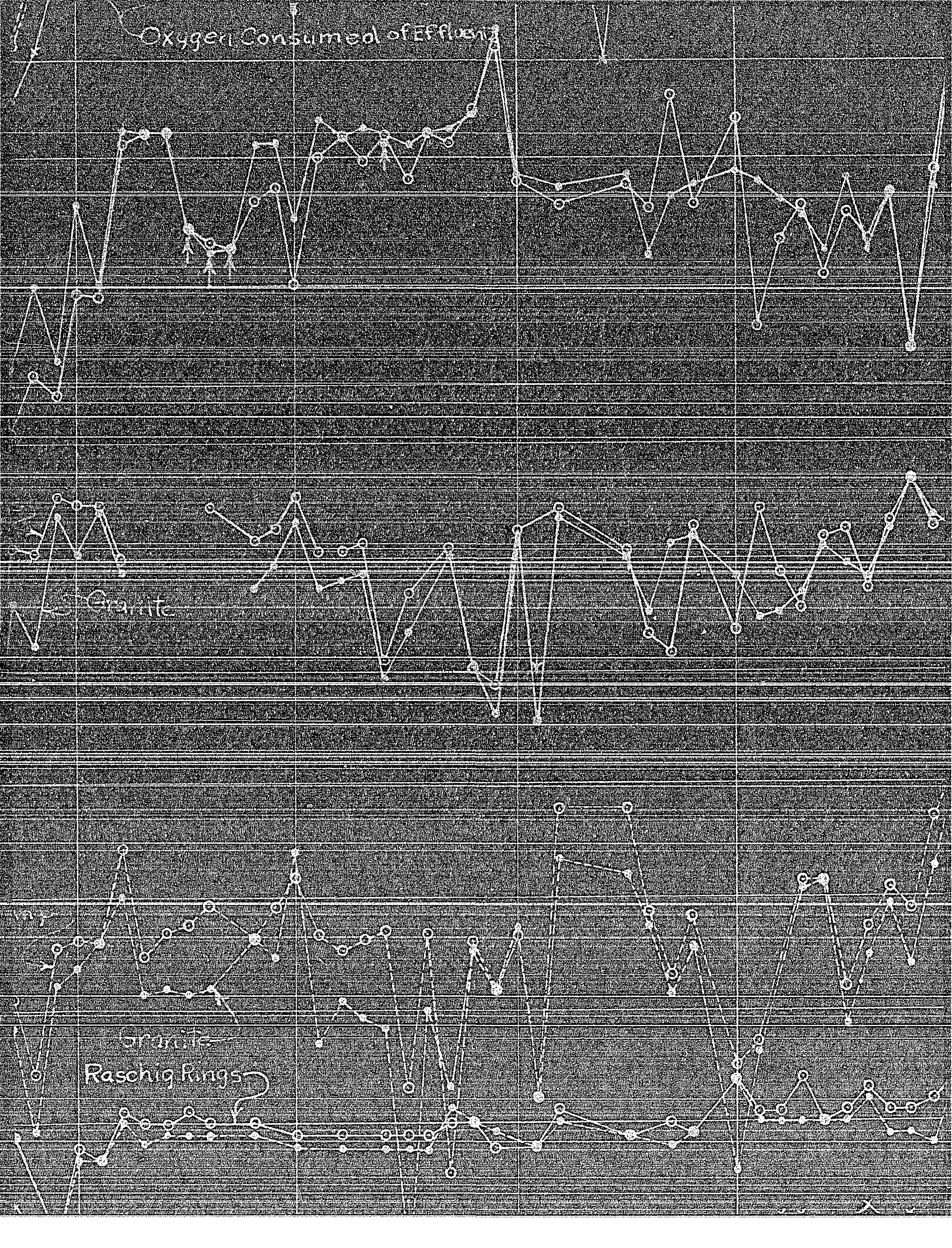


Fig. 2, p.34

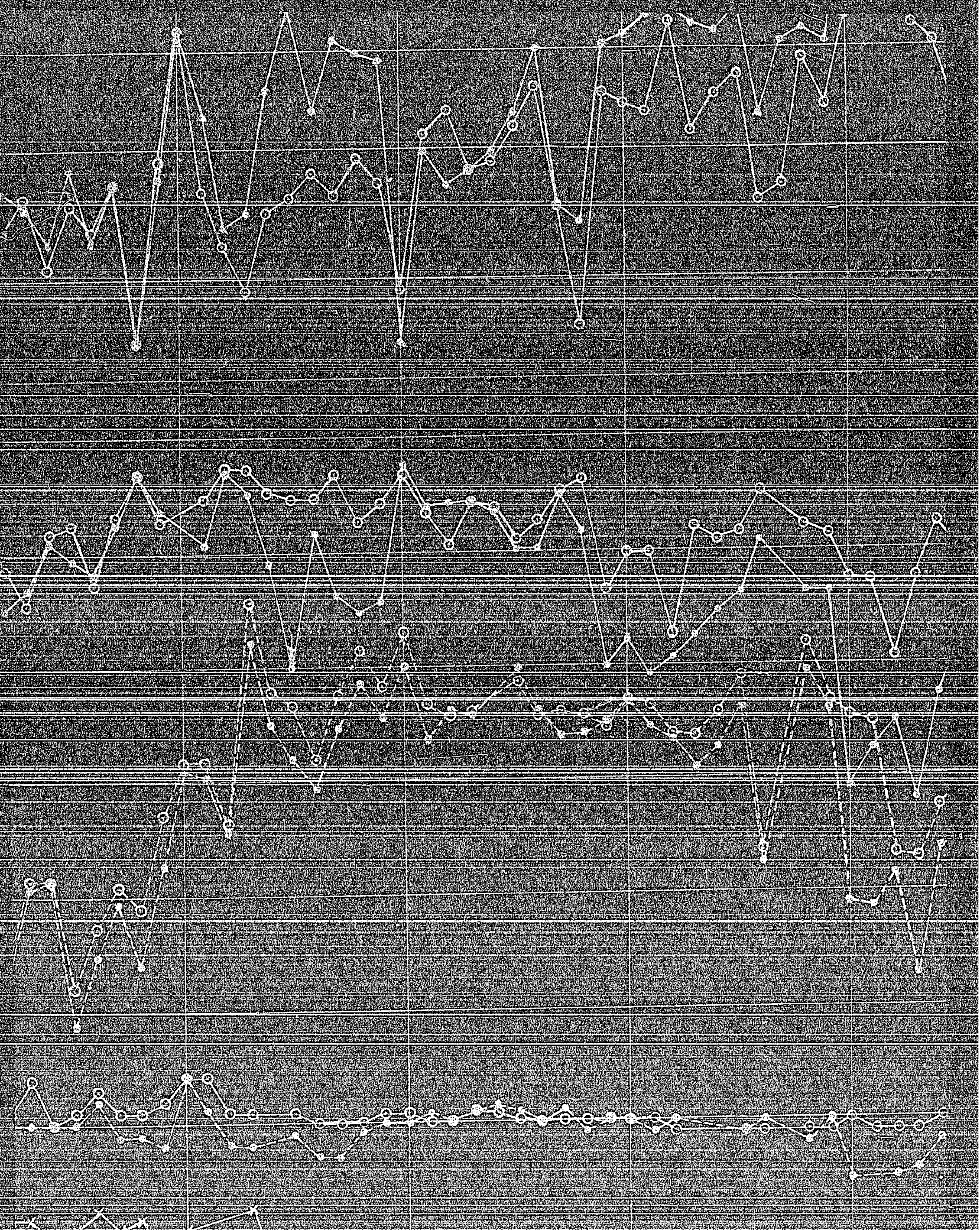


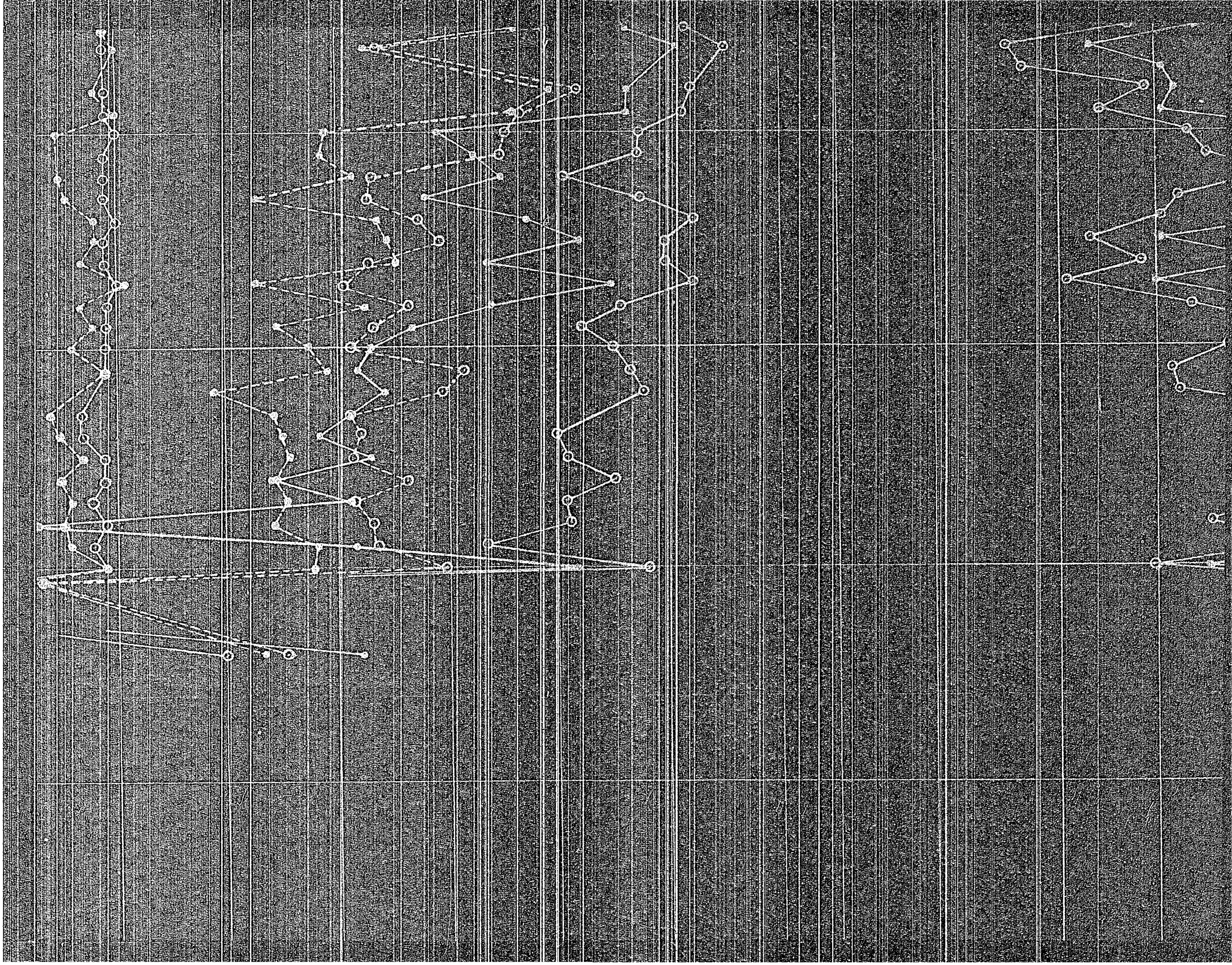


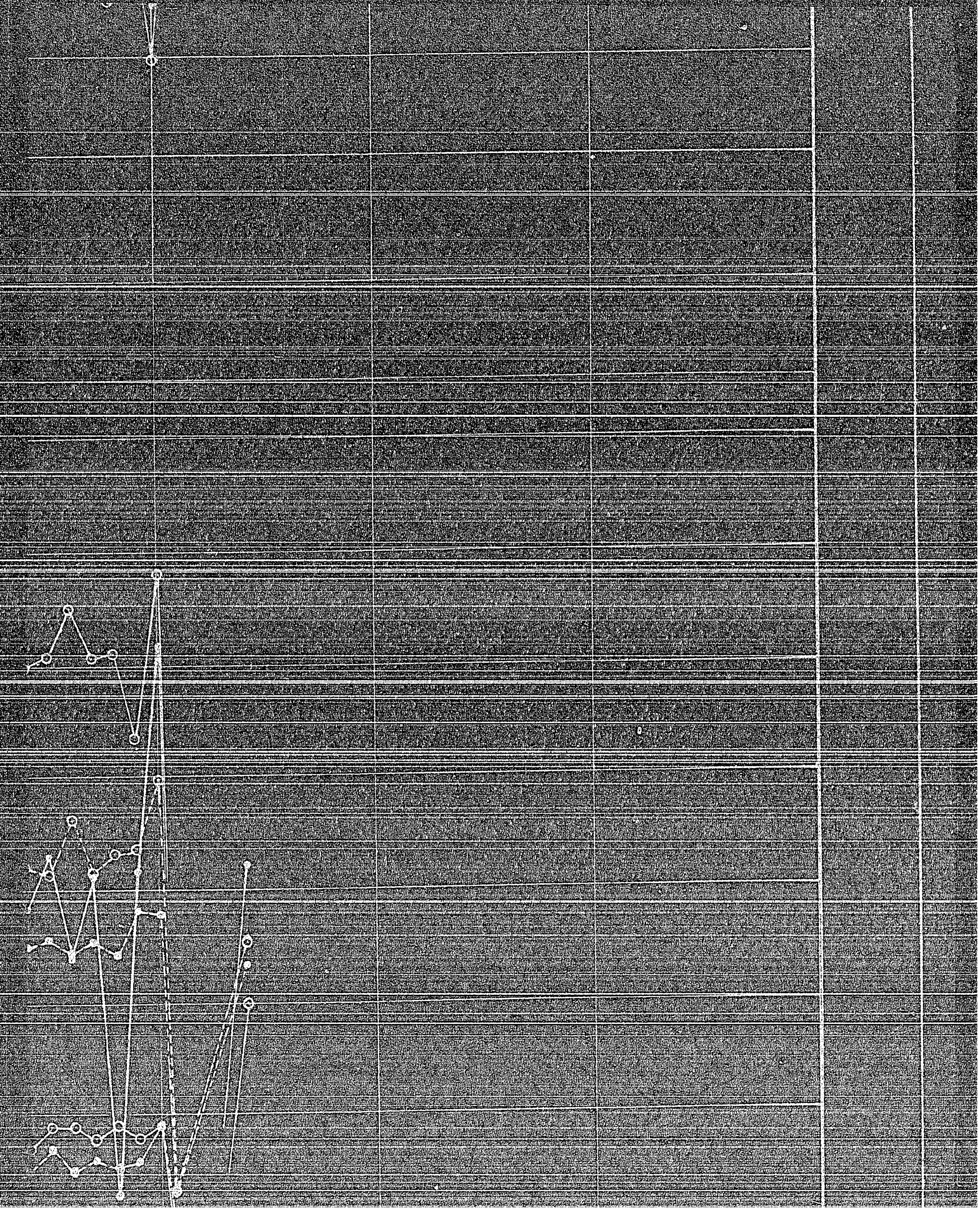
Concentration – ppm
100
50
20
10
BOD of Influent (I)
Oxyg
BOD of Effluents
Granite
Raschig Rings
100
90
80
70
60
50
Reduction – %
Raschig Rings
Granite
Reduction of BOD
Raschig Rings
Reduction of
Oxygen Consumed
Granite
Raschig Ri
Granite

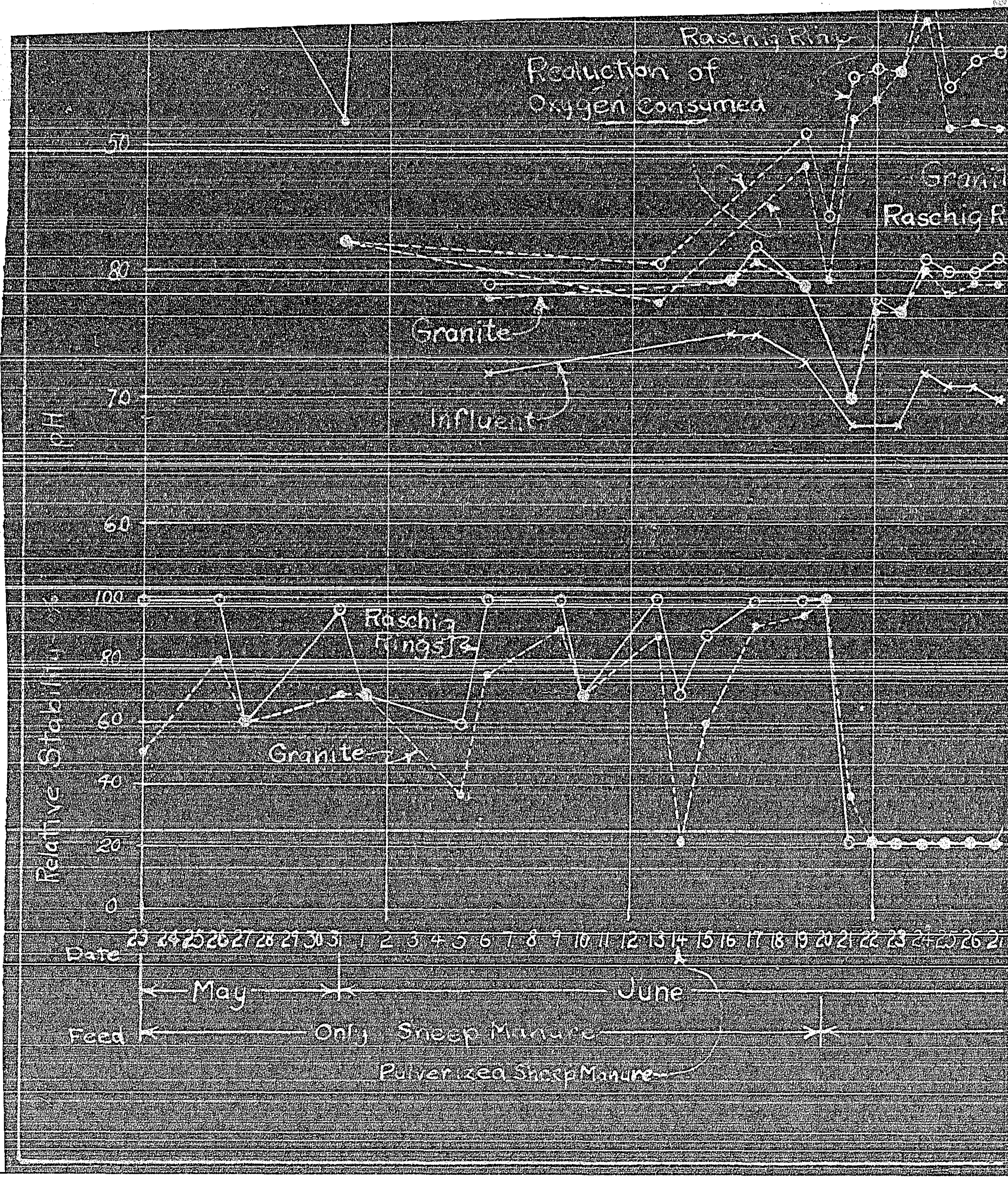


Oxygen Consumed of Effluent
Granite
Granite
Raschig Rings

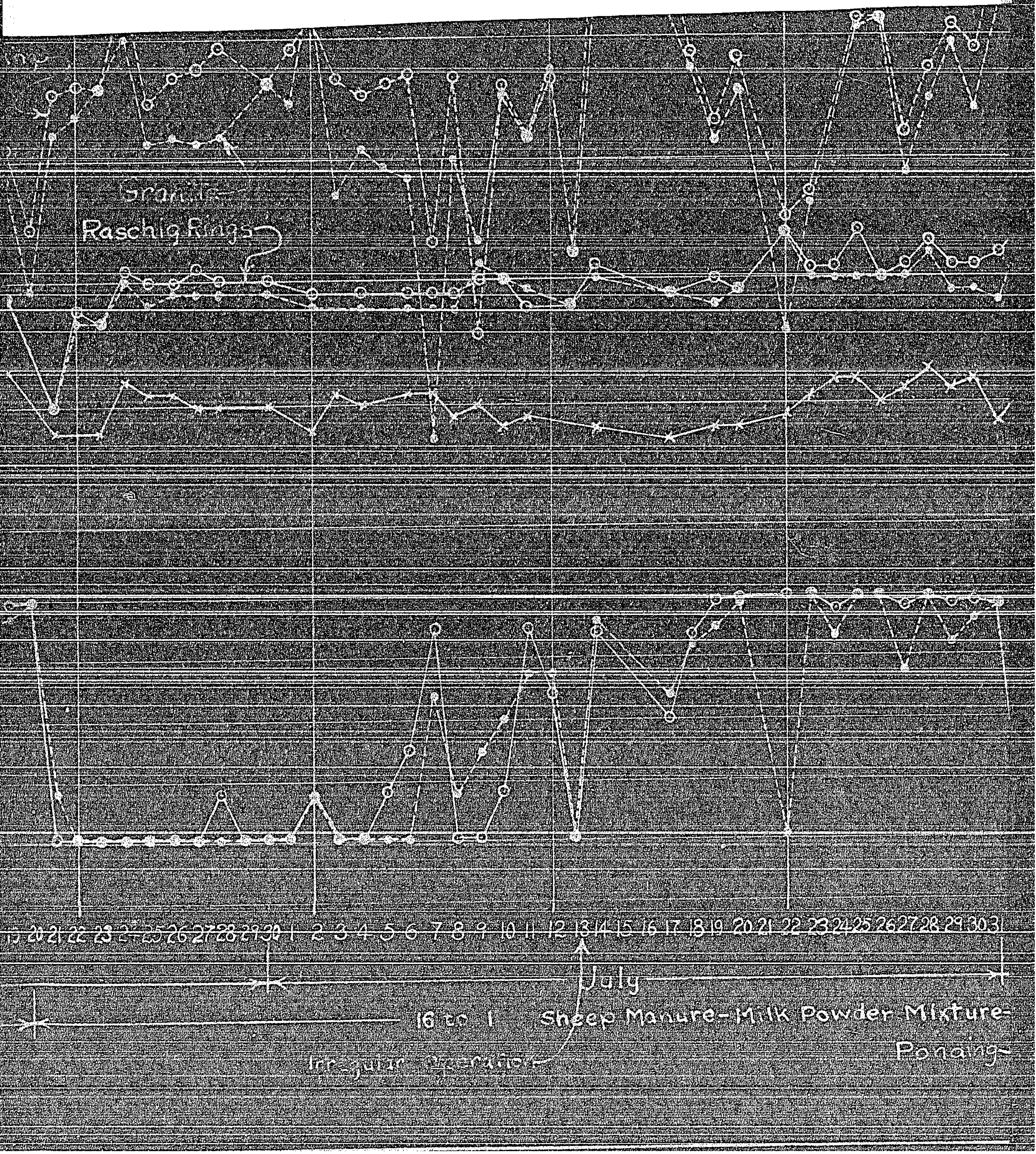




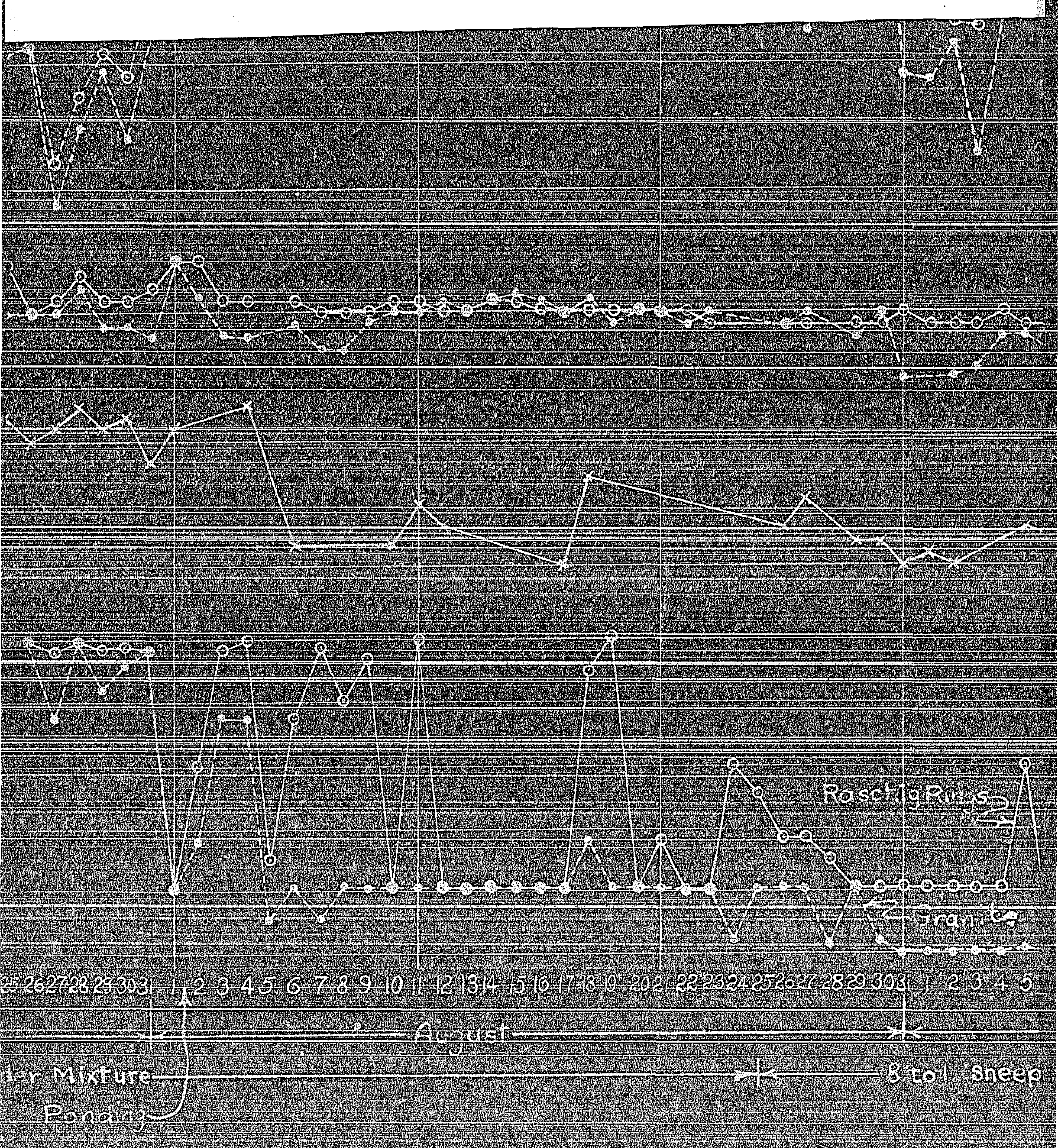


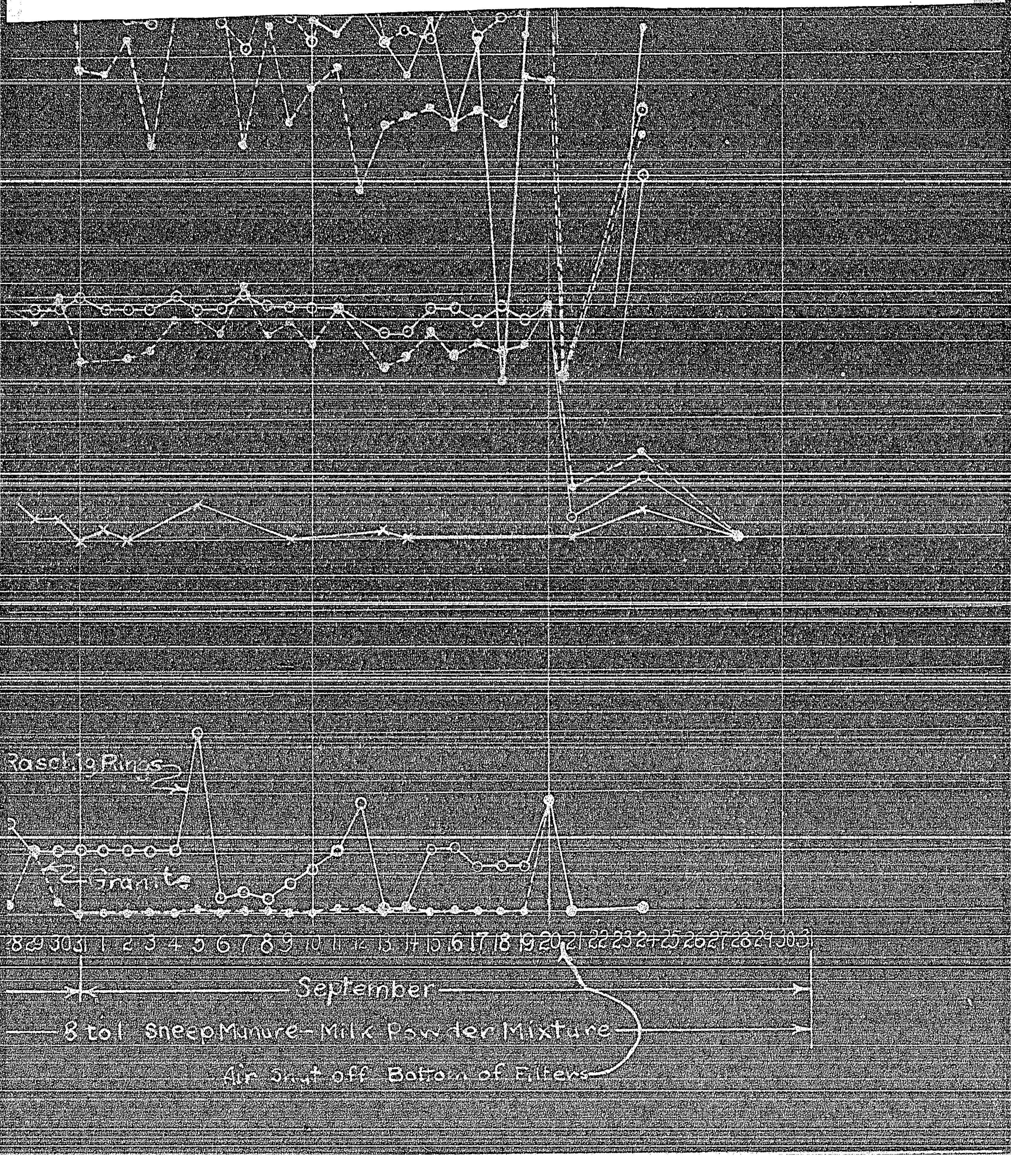


Raschig Ring
Reduction of
Oxygen Consumed
Granit
Raschig R
Granite
Influent
pH
50
80
70
60
100
80
60
40
20
0
Raschig
Rings
Granite
Relative Stability %
Date
23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
May
June
Feed
Only Sheep Manure
Pulverized Sheep Manure

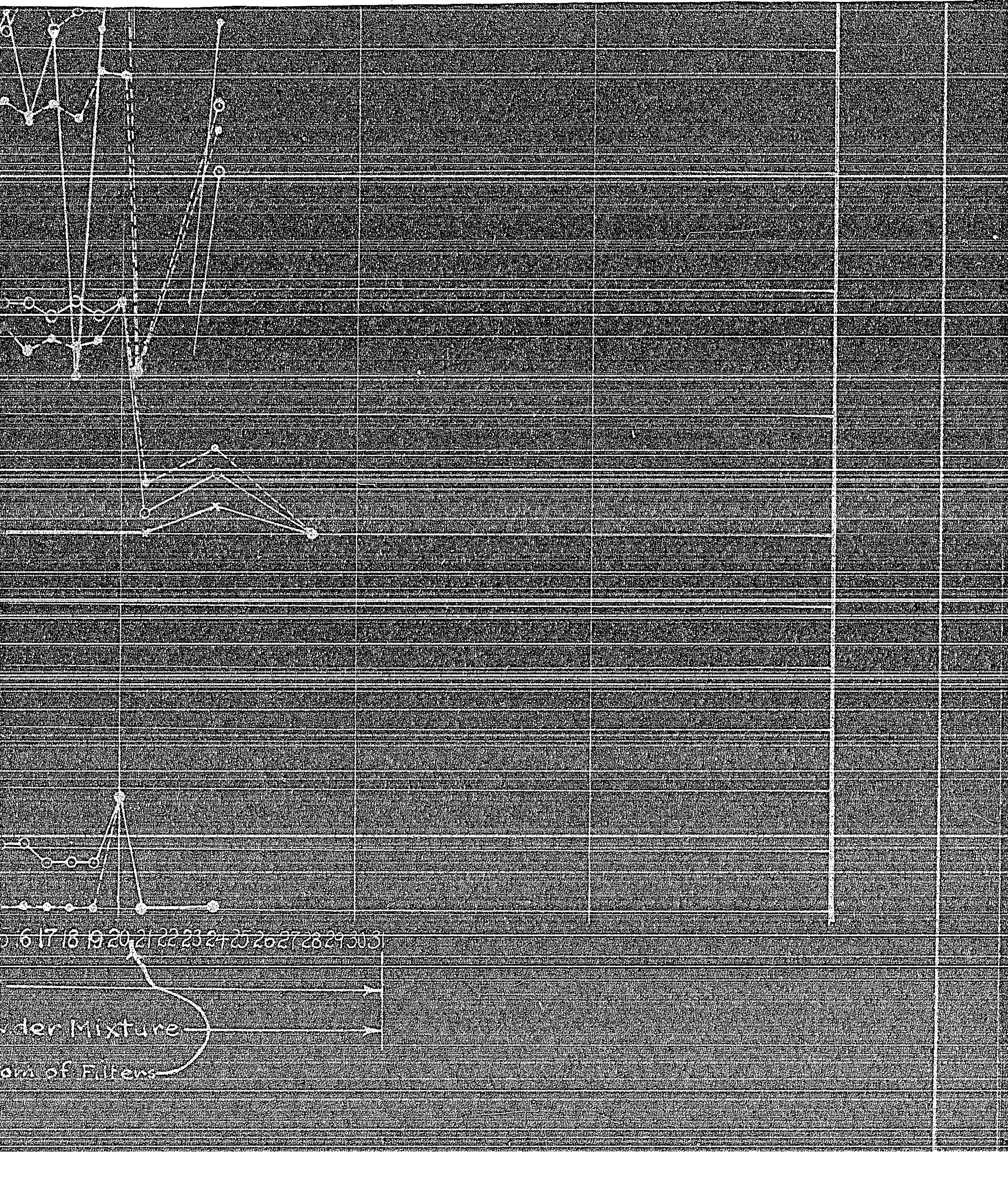


Granite
Raschig Rings
20 21 22 23 24 25 26 27 28 29 30 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
July
16 to 1 Sheep Manure-Milk Powder Mixture-
Ponang-


Raschig Rings
Granite
25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5
August
Mixture
8 to 1 Sheep
Ponding



Raschig Rings
Granite
28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
September
8 to 1 Sheep Manure-Milk Powder Mixture
Air Shut off Bottom of Filters



6 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
der Mixture
orn of Filters

pound of milk powder to 8 pounds of dried sheep manure was used and the average B.O.D. concentration of the applied waste was 999 p.p.m.

During the first two operating periods no abnormality of operation was observed in either filter. In the third operating period, however, some clogging occurred in both filters. In the case of the granite filter ponding occurred to a depth of several inches over the entire filter. In the case of the Raschig ring filter ponding was rather superficial, covering only small areas of the surface. In either case, however, the filters cleared themselves without the application of waste being stopped or other remedial measures being used.

The concentrations of the influents and the effluents both B.O.D. and oxygen consumed values, are shown on the top of Fig. 2. The solid lines represent the B.O.D. values and the broken lines the oxygen consumed values. Inspection of the curves representing the concentration of the influent show a great variation from day to day especially as to the B.O.D. This is principally due to variations in both the physical and chemical characteristics of the dried sheep manure. Manure in some of the bags was light weight, fibrous, and light in color; in other bags, it was dense, granular, and dark in color. The dry feeder fed the dense granular material at a higher rate than the light fibrous material. Furthermore, the dense granular material produced a greater amount of B.O.D. per pound of dry material than did the light fibrous material. The oxygen consumed values are more nearly a criterion of the carbonaceous material present than of the unstable organic material present. Since the carbonaceous material present in the waste is nearly proportional to the rate of feed of the dried sheep manure, the variation in oxygen consumed values are a reflection of the variation in rate of feed, expressed in pounds per day. On the other hand, since the dense granular material was not only fed at a higher rate but also produced a waste of greater concentration per pound of dry feed, a greater variation in B.O.D. values was to be expected.

In addition to the variation in sheep manure, already noted, some bags of the material contained quantities of balls of wool, wads of paper and lumps of earth. These foreign substances caused irregularity of feed which accounts for some of the extreme variations in concentration of applied waste.

No variation was noted in the milk powder. Upon long standing some change occurs in the milk powder, but the variation is not serious enough to cause trouble in work of this sort.

In general, it can be said that dried sheep manure was very unsatisfactory for the production of a synthetic waste.

In order to use this material, it is necessary that the material be ground to a uniform maximum size, and then mixed in large batches to insure uniform composition. The variation in concentration of applied waste due to a change in characteristics of the dried sheep manure was especially apparent on August 1. There was no change in the rate of feed at that time, but the B.O.D. concentration of applied waste changed from less than 500 on July 30 to over 1100 on August 1. The new shipment of dried sheep manure, which was first used on July 31, was a dense, dark brown, granular material. At this time a marked increase in oxygen consumed reduction occurred, with only a slight increase in B.O.D. reduction. This would tend to indicate that the entire nature of the applied waste changed at this time. It is possible that the waste contained a larger percentage of the more easily reduced carbohydrates, sugars, etc., and a smaller percentage of the more stable organic materials.

An interesting result was obtained on September 20. At this time the bottom of the filters were closed preventing bottom ventilation, the remainder of the setup being unchanged. The B.O.D. and oxygen consumed reductions immediately became very low, the pH of the effluents became very nearly that of the influent and the relative stability of the effluent became zero. In other words purification ceased almost immediately when bottom ventilation was stopped. The filters were not operated long enough under these conditions to become clogged although there was some indication that clogging was imminent when the experimental plant was taken out of operation.

The reductions in B.O.D. obtained in both filters are plotted in Fig. 3 and 4 as functions of the concentration of applied waste. Similarly the reductions in oxygen consumed are plotted as functions of the concentration of the applied waste in Fig. 5 and 6. Fig. 3 and 5 show the results obtained on the Raschig ring filter while Fig. 4 and 6 show the results obtained on the granite filter. Inspection of these curve sheets shows a very different reduction in B.O.D. reduction than oxygen consumed. The "scatter" or variance in the B.O.D. reduction data is not as great for the Raschig ring filter as for the granite filter. There is no marked difference in variance in the case of oxygen consumed reduction data.

Representative curves have been drawn through the points given on Fig. 3, 4, 5, and 6. These curves are shown on Fig. 7. It will be observed that the B.O.D. reductions obtained are low at very low concentrations of applied waste. As the concentration of the applied waste is increased the B.O.D. reduction increases until a maximum is reached at a concentration of about 400 p.p.m. with a reduction of about 95 per cent for the Raschig ring filter and about 93 per cent for the Granite filter. As the concentration of the applied waste is increased further, the reductions obtained are smaller

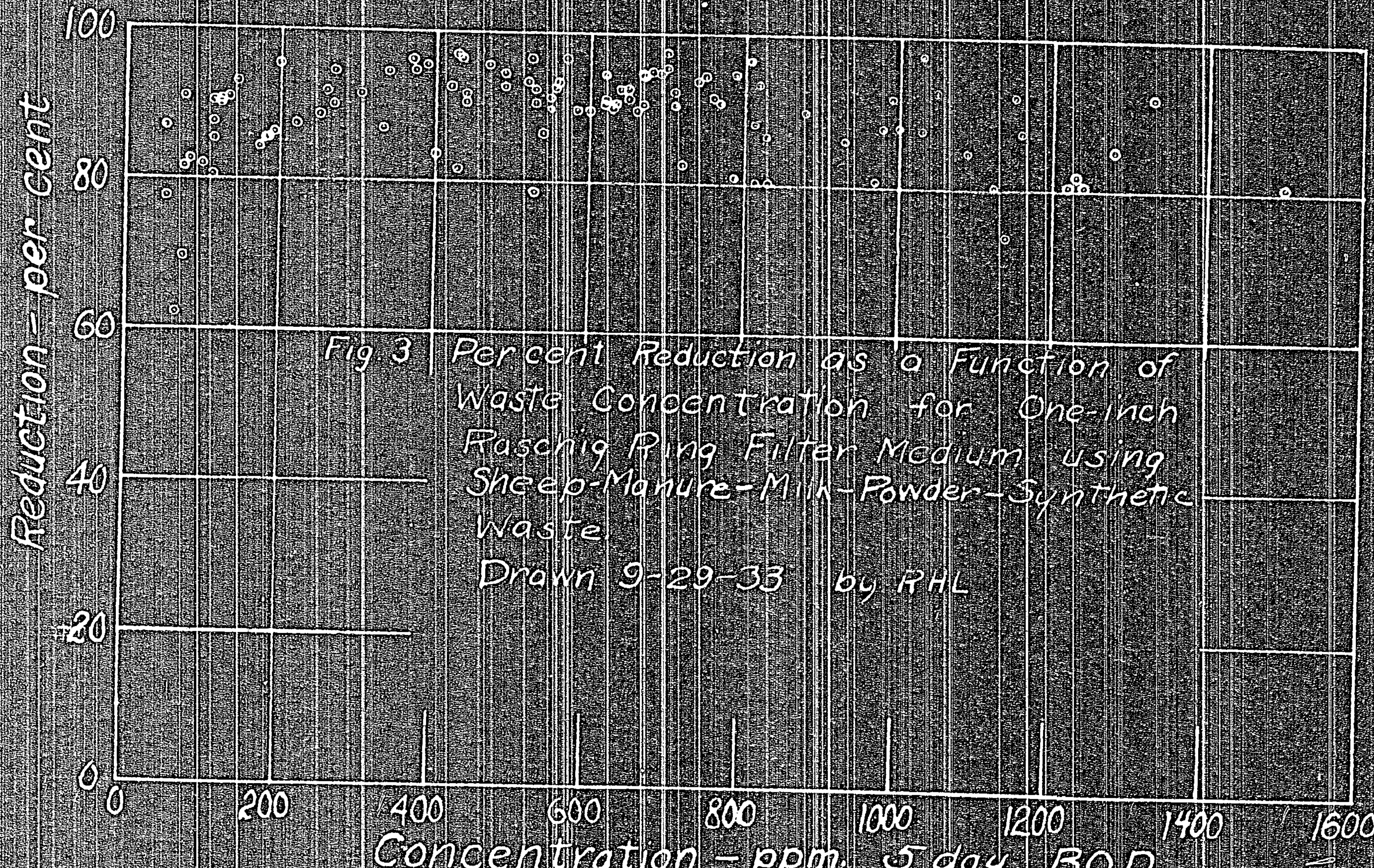


Fig 3 Percent Reduction as a Function of Waste Concentration for One-inch Raschig Ring Filter Medium using Sheep-Manure-Milk-Powder-Synthetic Waste.
Drawn 9-29-33 by RHL

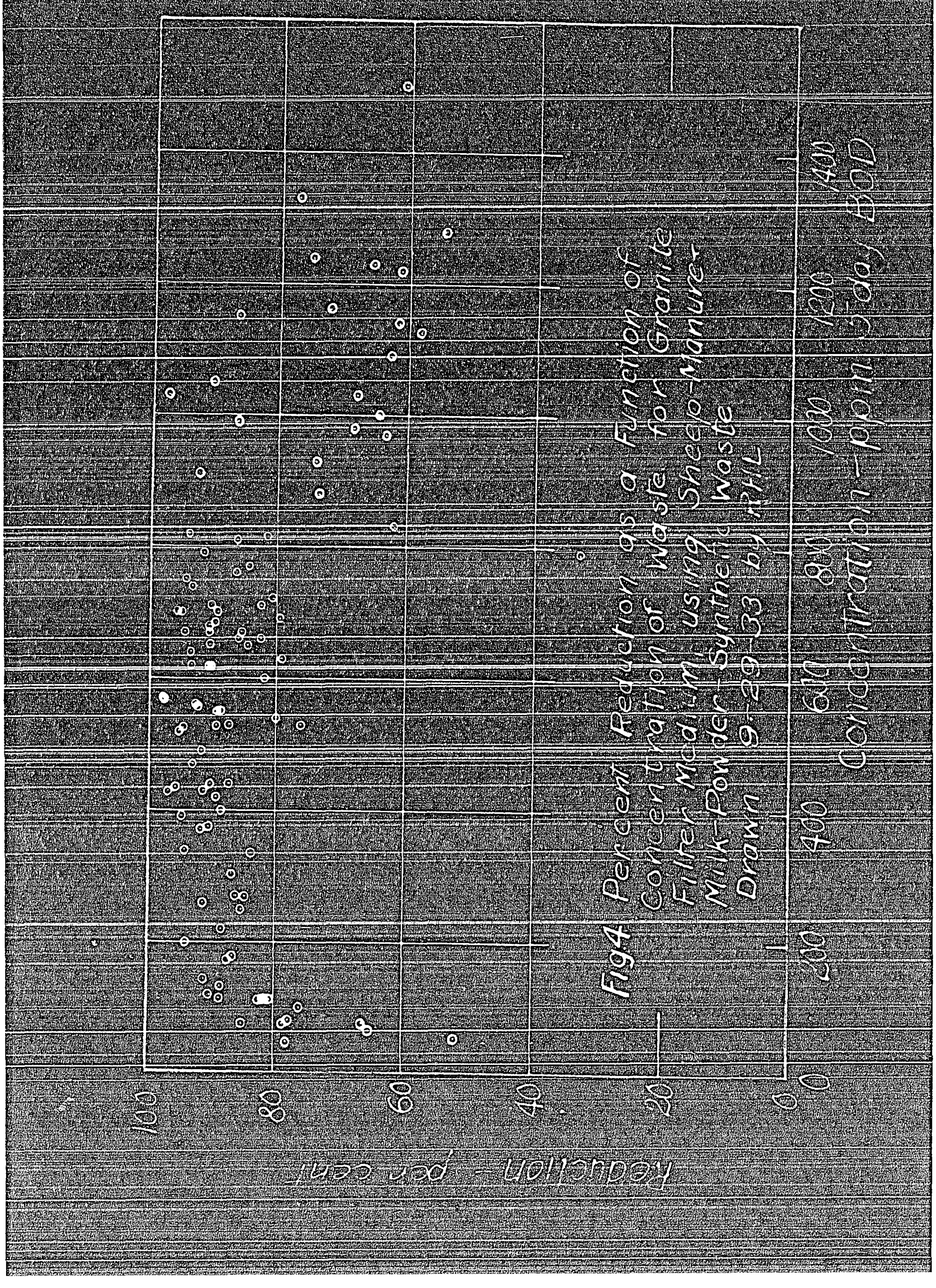


Fig 4 Percent Reduction as a Function of Concentration of Waste for Granite Filter Medium using Sheep-Manure-Milk-Powder-Synthetic Waste
Drawn 9-29-33 by RHL

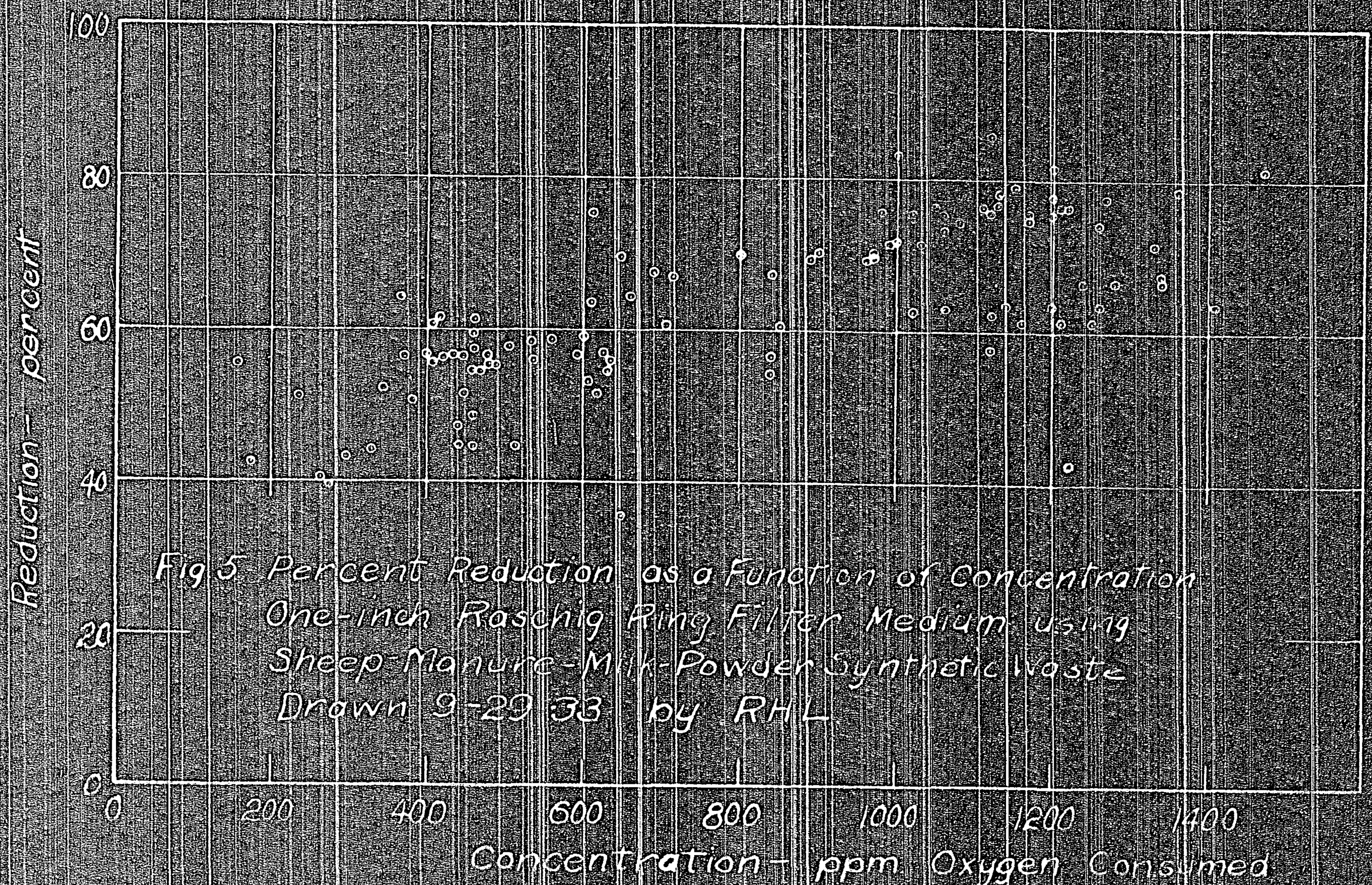


Fig 5 Percent Reduction as a Function of Concentration
One-inch Raschig Ring Filter Medium using
Sheep-Manure-Milk-Powder Synthetic Waste
Drawn 9-29-33 by RHL

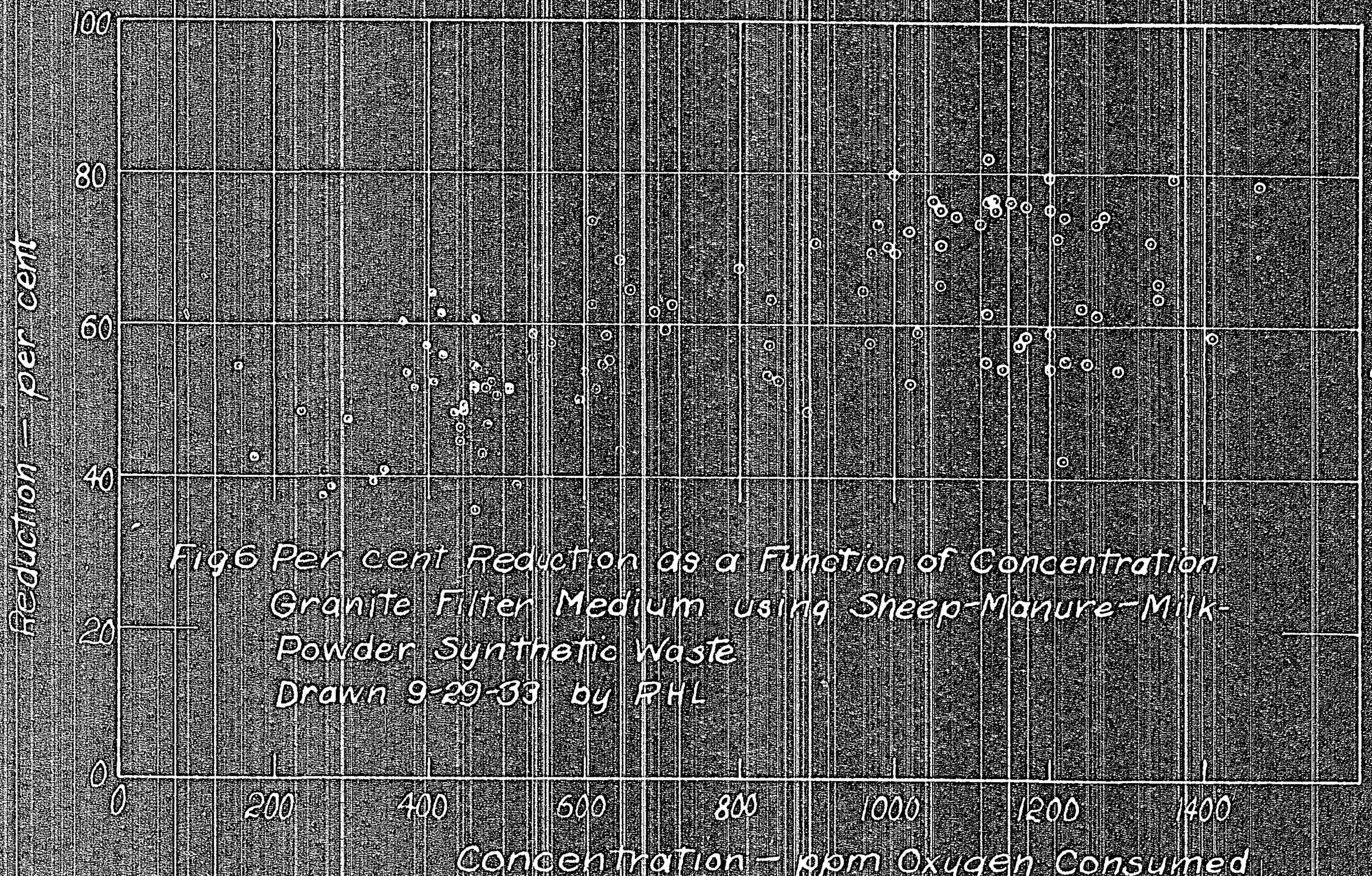


Fig.6 Per cent Reduction as a Function of Concentration
Granite Filter Medium using Sheep-Manure-Milk-
Powder Synthetic Waste
Drawn 9-29-33 by RHL

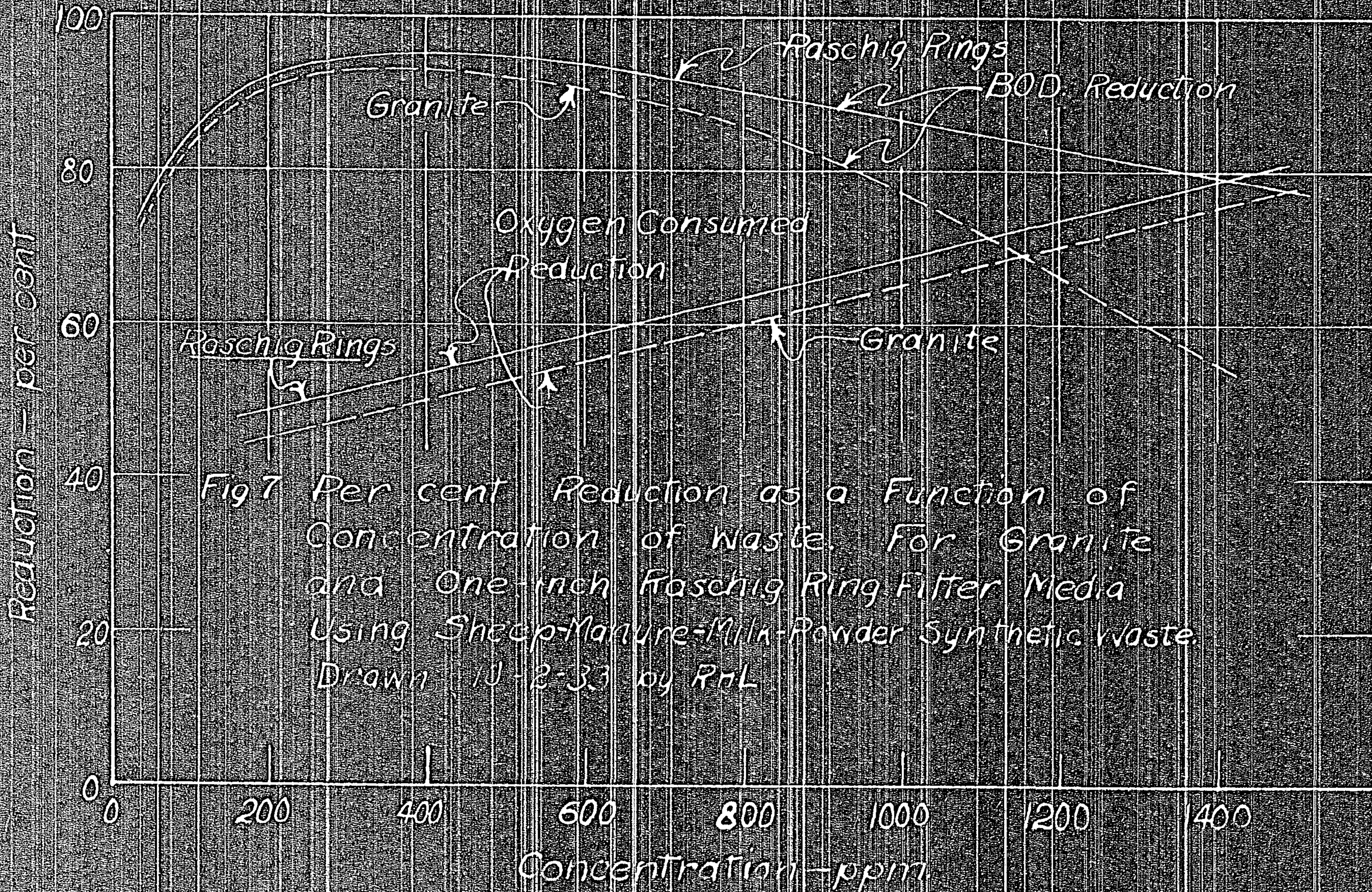


Fig 7 Per cent Reduction as a Function of Concentration of Waste. For Granite and One-inch Raschig Ring Filter Media Using Sheep-Manure-Milk-Powder Synthetic Waste.
Drawn 10-2-33 by RHL

and smaller until at a concentration of 1400 p.p.m. the reduction obtained on the Raschig ring filter is about 79 per cent and on the granite filter 55 per cent. It is to be noted that as the concentration of the applied waste is increased there is a more and more marked difference between the reductions obtained on the two filters. This increased difference is in part explained by the fact that the granite filter was more or less clogged during the period of greatest concentration of applied waste. The curves representing the reductions in oxygen consumed values are drawn as straight lines. The data in this case are somewhat more scattered than in the case of the B.O.D. reduction, and they did not appear to justify the drawing of any but a straight line. The curves shown represent the data as well as any other curves that may be drawn. It is to be noted that the reductions obtained on the Raschig ring filter are somewhat greater than on the granite filter. The per cent reduction appears to increase with increase of concentration of waste.

For some wastes there is a constant relationship between the B.O.D. and oxygen consumed values. The ratio between these values may be constant for a given waste, but this ratio does not hold for any other waste. It is of interest to note something of the relationship between these values for the waste used in this experiment, especially since the concentration of the applied waste varied over a considerable range. The data obtained in this experimental run are plotted on Fig. 8 to show the relationship between the B.O.D. and oxygen consumed values, both for the influents and effluents. In general the oxygen consumed values are about 1.2 of the B.O.D. values even though this relationship is far from rigid. It appears possible that the relationship may be a curvelinear function.

A summary of the data obtained in the preliminary experiment is shown in Table No. 2. The values shown are averages of the data obtained during each of the three operating periods. The B.O.D. removal obtained from the Raschig ring filter is greater than that of the granite during the first operating period, distinctly greater during the second period and very markedly greater during the last period. The reductions in oxygen consumed values are not as striking. During the first and second operating periods there was no significant difference in oxygen consumed values but in the third period the reduction obtained on the Raschig rings is somewhat greater. The relative stabilities of the effluents while somewhat better on the Raschig ring filter are not significantly so. There is no significant difference in the pH of the effluents. It is to be noted, however, that both filters converted an acid waste to an alkaline effluent; changing a waste with a pH of 6.2 to an effluent with a pH of 7.9 or

Fig. 8. Data Showing Relationship between BOD and Oxygen Consumed Values.
x Influent (I)
o Raschig Rings (R)
• Granite (G)

Drawn 10-2-33 by RHL

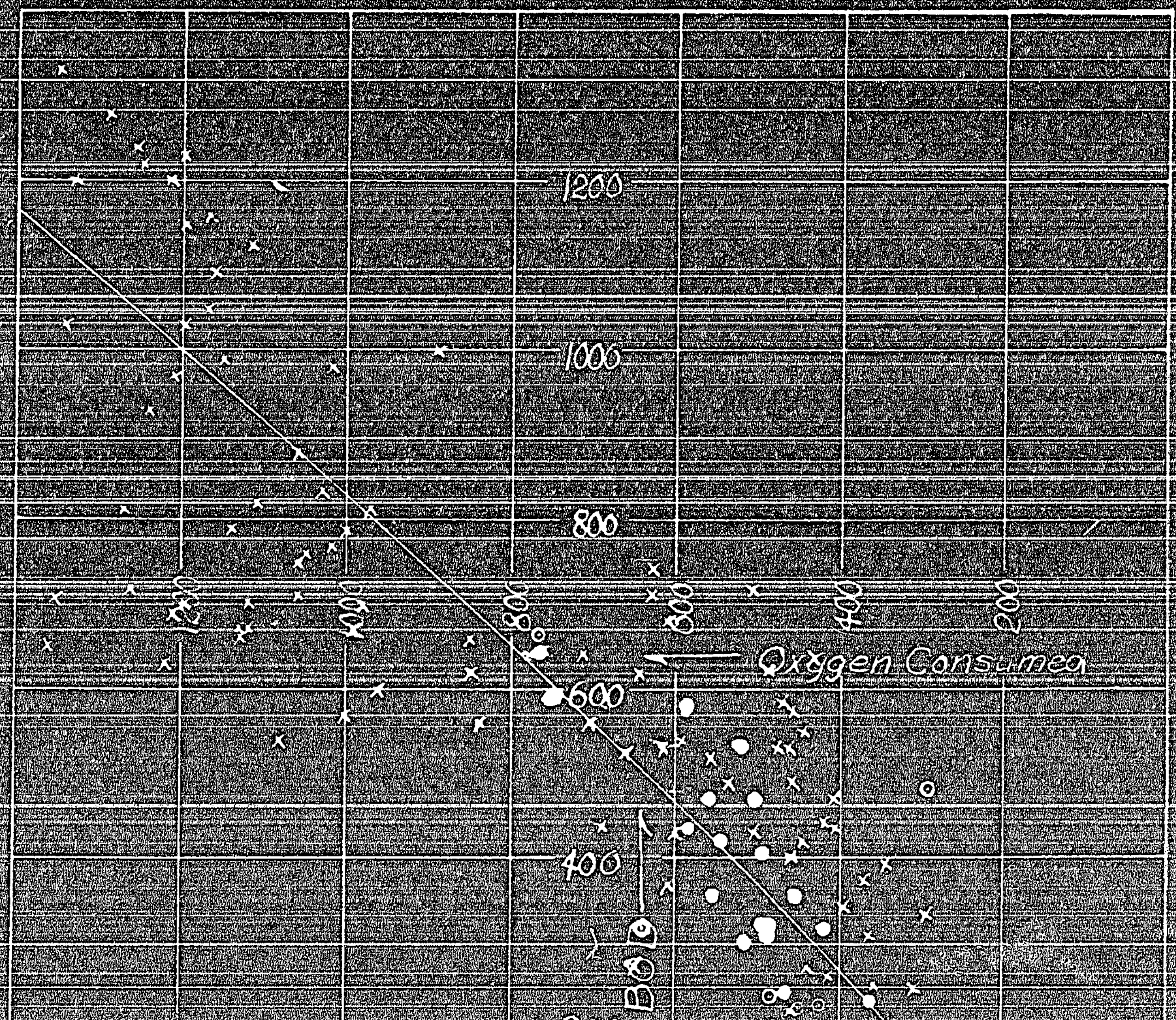


Table No. 2 Summary of Data Obtained in Preliminary Experiment.

Period	B.O.D. - p.p.m.			Oxygen Consumed - p.p.m.			Relative Stability - %	
	Inf.	R	G	Inf.	R	G	R	G
1	117	18.5	21.5	320	152	159	84	70
2	567	46.1	58.1	729	246	259	56	43
3	999	146	309	1113	384	449	21	4

Period	PH			Nitrates			Nitrites	
	Inf.	R	G	Inf.	R	G	R	G
1	7.4	8.0	7.9	-	-	-	-	-
2	6.9	6.9	7.9	2.50	6.06	5.90	.31	.36
3	6.7	7.9	7.7	4.50	6.66	3.90	-	-

Period	Free Ammonia			Dissolved Oxygen	
	Inf.	R	G	R	G
1	-	1.6	2.1		
2	5.8	5.6	10.0	0.84	0.70
3	14.2	43.2	39.7	0.30	0.03

Dosage
2 M.G.A.D., 6 min. cycle.

Period
1 - Sheep manure only.
2 - 16 to 1 sheep manure - milk powder.
3 - 8 to 1 sheep manure - milk powder.

Sample R - one inch Raschig Ring filter.
G - 1 to 3 inch crushed granite filter.

thereabouts. Nitrification was carried further in the Raschig ring filter than in the Granite filter. In the third period, for example, the influent contained 4.5 p.p.m. of nitrates. The effluent from the Raschig ring filter showed an increase of nitrates to 6.66 p.p.m. while the granite filter showed a decrease to 3.9 p.p.m. of nitrates.

The conclusions to be derived from this preliminary experiment may be considered under three heads: those applying to Raschig ring and granite filters in particular, those applying to trickling filters in general, and those concerning the production of a synthetic waste.

It may be concluded from the observations on the waste used:

1. That for low concentrations, up to 400 p.p.m. B.O.D. there was no substantial difference in the average reductions obtained with the granite and one-inch Raschig ring filter media.

2. That at higher concentrations the one-inch Raschig ring filters showed substantially greater reductions in B.O.D.

3. That the tendency toward clogging and irregular operation was substantially less in the one-inch Raschig ring filter than in granite.

Evidence is presented that bottom ventilation is necessary for the successful purification of concentrated wastes by trickling filters. This evidence is a substantiation of the earlier work of Levine (25) on filter ventilation.

Evidence is presented to show that trickling filters have the ability to treat much heavier wastes than previously thought possible. It is possible that present day trickling filters are overdesigned.

The attempt to use dried sheep manure for the production of a synthetic waste having constant characteristics, has shown this material to be very unsuitable for this purpose. It has been found to vary both by way of physical properties such as size, shape and density of particles, and foreign materials present, and also by way of chemical properties, such as per cent solubility, B.O.D. production, volatile constituents, nitrogen content, etc.

B. Experimental Plant at City of Ames Sewage Disposal Plant

1. Objectives.

The preliminary investigation indicated that Raschig rings have definite merit as filter media. Furthermore, evidence was presented that filters may be operated at a much higher rate than is customarily used. The use of the synthetic waste employed was found to be impractical for the purpose at hand.

A more detailed investigation was projected having the following objectives:

a. To obtain additional information concerning the feasibility of using ceramic products as trickling filter media.

b. To obtain information concerning the optimum size of medium for commercial use.

c. To obtain information concerning the relationship between the physical characteristics of the medium, such as surface free air space, and interstice size, and the purification obtained.

d. To obtain information concerning the limiting rate of waste application for a trickling filter.

e. To obtain information concerning the limiting factors in trickling filter operation.

2. Equipment.

a. Plant location.

An experimental trickling filter plant was built and operated at the sewage disposal plant of the city of Ames. Fig. 9 shows a picture of the Ames Sewage Disposal plant looking toward the northwest across the city trickling filter bed. The brick structure in the center of the picture houses an Imhoff tank. In the center of the picture and partly obscuring the Imhoff tank is a wooden "leanto" building

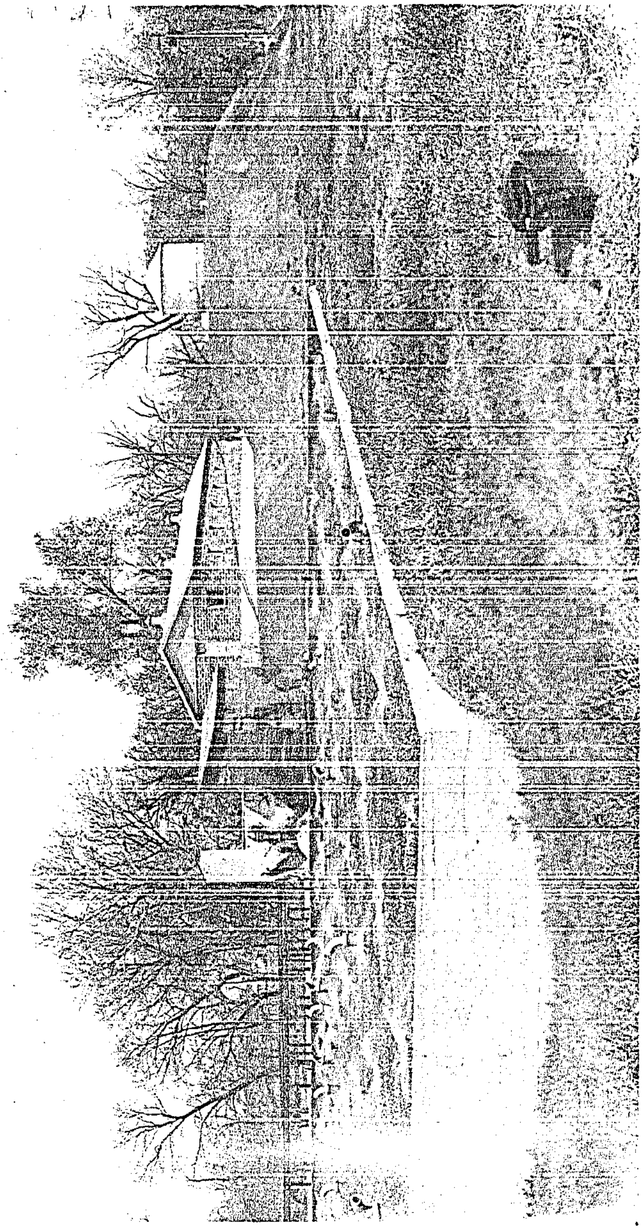


Fig. 9

which housed the experimental trickling filter plant. Settled sewage discharged from the city Imhoff tank was used as influent to the experimental plant.

b. Filter Media.

As in the preliminary investigation, 1 to 3-inch crushed South Dakota quartzite was used in the control or standard filter.

Four sizes of Raschig rings were used in this investigation: three-fourths inch, one inch, one and one-half inches, and two and one-fourth inches. The one-inch rings used in the preliminary investigation were again used in this investigation. One yard of each of the other three sizes was made in the Ceramic Engineering Laboratories of Iowa State College, under the direction of Professor Paul Cox. Iowa clays from various sections of the state were used as the raw material for these rings. The rings used in the preliminary investigation were not burnt very hard. The other three sizes were burnt to a somewhat higher temperature.

The ceramic products used in this experiment can be readily produced from almost any of the Iowa clays. No special preparation is required, save for the screening out of pebbles and other foreign material which would clog the die. The rings were made by extruding from an augur machine, followed by hand cutting. In a commercial plant an automatic cutting device would be used. Following the cutting operation the rings would enter a preliminary dryer for a few minutes. After preliminary drying, the rings are strong enough to withstand considerable handling. A short drying period of an hour or two will prepare the rings for firing.

The rings used in this investigation were only partially vitrified. This investigation did not include an investigation of the freezing and thawing resistance of the rings. It was not felt that this was essential for this study, inasmuch as the rings can readily be burnt to any degree of vitrification required to resist freezing and thawing. In practice it is becoming less and less necessary for the filter medium to withstand freezing and thawing, even though some authorities require the medium to be used to withstand a freezing and thawing or a sodium sulphate disintegration test.

It is possible, because of the low draft loss through a bed of Raschig rings, to fire directly through a bed of rings. No ducts, channels or other draft device is necessary. In the production of the rings used in this investigation, a pottery kiln, designed for firing material in sagers, was filled completely full of rings and fired directly through the rings. No unevenness of firing was noted, nor was the draft loss excessive. Because of the very thin walls of the rings a very short firing period can be used.

A special block was designed and built by Mr. H. R. Straight of the Adel Clay products Co., after inspecting the preliminary experiment, and referred to as Straight's block, and was used in filter number 6. This block is a modified building block having 4 star shaped vertical channels in each block. The block is roughly 4 1/4 inches square in a horizontal plane and about 2 1/2 inches in depth. A top view of the block in place in the filter with the microbial film developed is shown in Fig. 17.

Filter number 7 contained corncobs cut into 2 inch lengths. A picture showing the corn cobs in place in the filter and with the microbial film developed is shown on Fig. 20.

Physical Constants of Filter Media

The relationship between surface of a medium per unit volume and the size of medium, is shown on Fig. 10. The values shown were obtained from various sources as indicated. The principal physical constants of the media are given in Table No. 3. The actual dimensions of the Raschigs rings are averages of measurements on one hundred rings collected at random while placing the rings in the filters. The number per cubic foot was determined by counting the number of rings contained in a box of about 1 3/4 cubic foot capacity. The weight per cubic foot was determined by determining the weight contained in this measuring box. The surface area per cubic foot was calculated by considering the rings as hollow cylinders, considering the area as the sum of the inside and outside areas of the cylinder and the annular ring area on each end. The per cent of voids was arrived at by calculating the volume occupied by the rings, and subtracting from the total volume.

Whisler (32) determined, by actual measurement, the surface area of the rock contained in a given volume of filter. The per cent of voids was calculated from a knowledge of the actual density of the granite and the apparent density in the filter.

The physical constants of Straight's block were calculated on two bases, first considering the block stacked according to theoretical dimensions, as they would be in a large bed, and second as they were stacked in the experimental filter. In the experimental filter it was necessary to leave some vacant space in each layer in order to stagger the blocks properly. In other words, it is theoretically possible to place 34.4 blocks per cubic foot. In the experimental filter only 27.08 blocks were used per cubic foot. The weight per cubic foot is based on the average weight of a number of blocks. The surface per cubic foot is calculated from the measured area of one block. Roughness was not taken into consideration in measuring the area of a block. The star shaped channels were quite rough due to an improperly designed die used in making

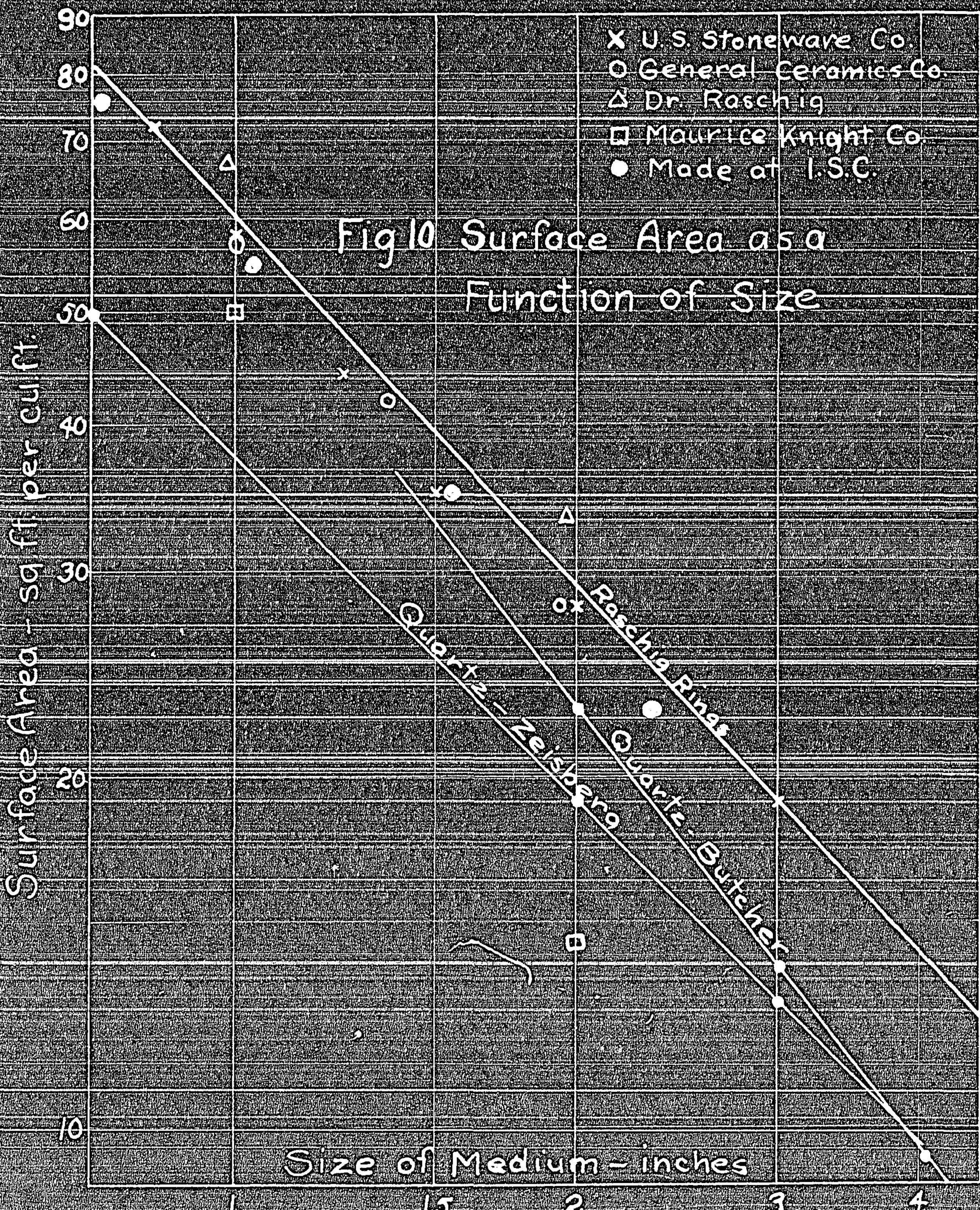


Fig 10 Surface Area as a Function of Size
X U.S. Stoneware Co.
O General Ceramics Co.
Δ Dr. Raschig
□ Maurice Knight Co.
● Made at I.S.C.
Raschig Rings
Quartz - Butcher
Quartz - Zeisberg
Surface Area - sq ft per cu ft.
Size of Medium - inches
90
80
70
60
50
40
30
20
10
1
1.5
2
3
4

Table No. 3 PHYSICAL CONSTANTS OF FILTER MEDIA

Material	Length inches	Outside Diameter inches	Inside Diameter inches	Number of Units per cu. ft.	Weight lb. per cu. ft.	Surface area sq. ft. per cu. ft.	Voids per cent	
Granite								
1½-3 in.						23.4	37	(a)
						19.0	46	(b)
					90.53	29.98	45.3	(c)
Raschig Rings								
¾ in.	0.7797	0.7926	0.4845	2925	46.87	75.8	59.36	(d)
1 in.	1.025	1.081	0.6546	1174	49.72	52.2	58.14	(e)
1½ in.	1.5685	1.649	1.042	340	40.81	35.0	68.21	
2½ in.	2.341	2.342	1.750	97.3	30.30	22.7	74.93	
Straight's Block								
Theoretical				34.4	56.3	35.8	53.1	(f)
Actual				27.08	44.25	28.2	63.1	(g)
Corn Cobs					13.3			(h)

(a) Value given by Butcher.
(b) Value given by Zeisberg.
(c) Value determined by Whisler.
(d) Dimensions of rings are averages of measurements of 100 rings selected at random. The number and weight of rings per cubic foot were determined by counting and weighing the contents of a box of 1.7288 cu. ft. in volume. The surface area and per cent voids were calculated from these measurements, assuming the rings to be cylinders.
(e) The one-inch rings were made one year previous to the other sizes and have somewhat heavier walls.
(f) The theoretical values were obtained by measurement of blocks, assuming theoretical packing conditions.
(g) It was impossible to completely utilize all available space when the blocks were packed in the experimental filters. The values given are those obtained in the filter.
(h) The corn cobs were cut into about two-inch lengths. The weight given is for air dried cobs.

the block. As a result of this the surface area given is probably low. The percentage voids is calculated from the volume of solid material per block and the volume occupied by one block.

For obvious reasons, it is not possible to make any statement of the surface in the case of the corn cobs.

The granite, the Raschig rings and the corn cobs were placed in the filter without any attempt at stacking or other arrangement. The media may be said to have been dumped. In the case of Straight's block the material was carefully stacked in the filters, alternate courses being offset. Twenty-five blocks were used in each course.

c. Dosing device and filter construction.

A schematic diagram of the experimental trickling filter plant is shown on Fig. 16. According to this diagram, a motor driven gear pump lifts the sewage from the Imhoff tank discharge into a distributing trough. This trough is connected with seven weirs over which sewage flows into the dosing tanks for each filter, an overflow siphon to waste sewage, a quick opening waste or drain valve and the influent sampler. Each of the seven dosing tanks is fitted with a movable partition for varying the capacity of the tank, and a quick opening valve for discharging the sewage onto the perforated metal distributing trays. The distributing trays are a few inches below the dosing valve and about eight inches above the filter media.

The dosing cycle occurs in the following fashion: The pump is discharging continuously into the distributing trough. When the drain valve is closed the sewage flows over the seven small weirs into the seven dosing tanks. As soon as the dosing tanks are filled the liquid level in the distributing trough rises until the overflow siphon is started and carries away the excess waste. At this point the motor operated drain valve opens and drains the distributing trough and drains the liquid in each of the dosing tanks to the level of the weir in that tank. At the appropriate time the motor operated dosing valve is opened, discharging the contents of the dosing tank onto the distributing tray. The dosing and drain valves are again closed completing one dosing cycle.

The size of the dose is determined by the capacity of the dosing tank and is readily maintained constant. The time of the dosing cycle is maintained constant by means of an adjustable rachet drive mechanism shown in Fig. 13 and 18, which maintains an unusually uniform dosing cycle.

Fig. 11 and 12 show the top of the filters, the distributing trays and the dosing device. The long shaft seen at the top of both pictures operates the quick acting dosing valves. The vertical chain on the left side of Fig. 13 is connected with this shaft by means of pulleys on the ceiling. The motor driven operating mechanism is just visible on the right side of Fig. 12. The distributing trough with round holes containing the weirs leading to the dosing tanks, is in the foreground of Fig. 12. The clamps holding the movable partition and part of the movable partitions are visible in both Fig. 11 and 12. The pump discharge into the distributing trough and the influent sampler are just visible in the upper right hand corner of Fig. 12.

The dosing tanks, distributer trough and filter cases were constructed of thoroughly painted wood. The seven filter cases, each 24 inches on a side, inside dimensions, were built side by side, with one common wall between filters. The bottom of the filters is shown in Fig. 14 and 15. Filters No. 1 and 2 are shown in Fig. 14. The common wall between filters is plainly visible in the center of this picture. The dark holes visible in Fig. 14 and 15 are the bottom ventilation ports, 4 inches in diameter.

A 16 mesh to the inch screen was used on the inlet pipe to the pump to exclude grit and other foreign material which might injure the pump or clog the distributing trays. A geared pump, which is shown in the lower left hand corner of Fig. 13, was used in this set-up. This type of pump delivers a constant volume of waste, even though the head may vary. The wear on this type of pump, however, is considerable. After being in operation for about one year, the pump was nearly worn out, though it should be stated that the pump was not new when the experiment was initiated. 2-inch rubber toilet flush ball

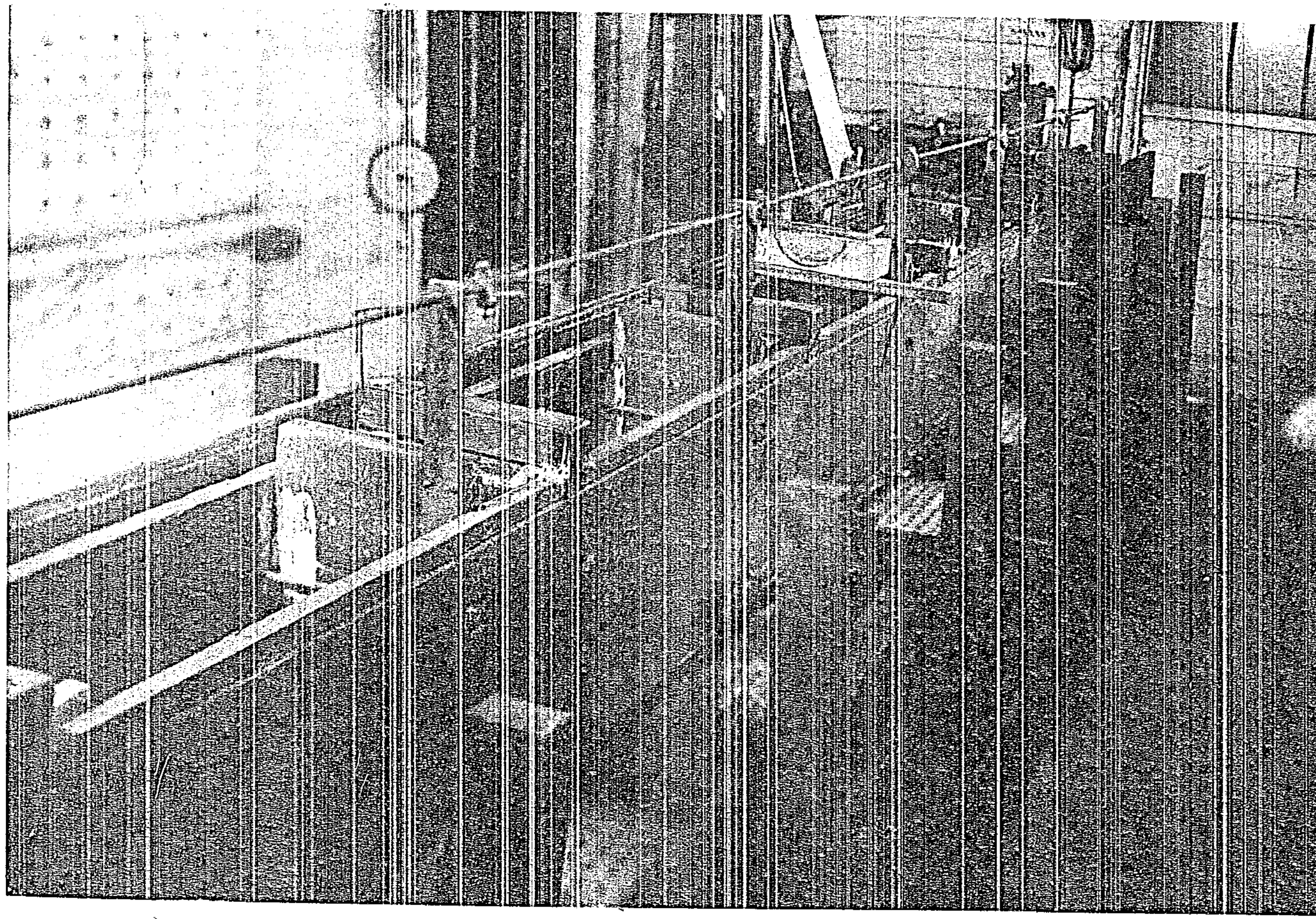


Fig. 11 Top of Filters and Dosing Device from Northwest Corner of Second Floor

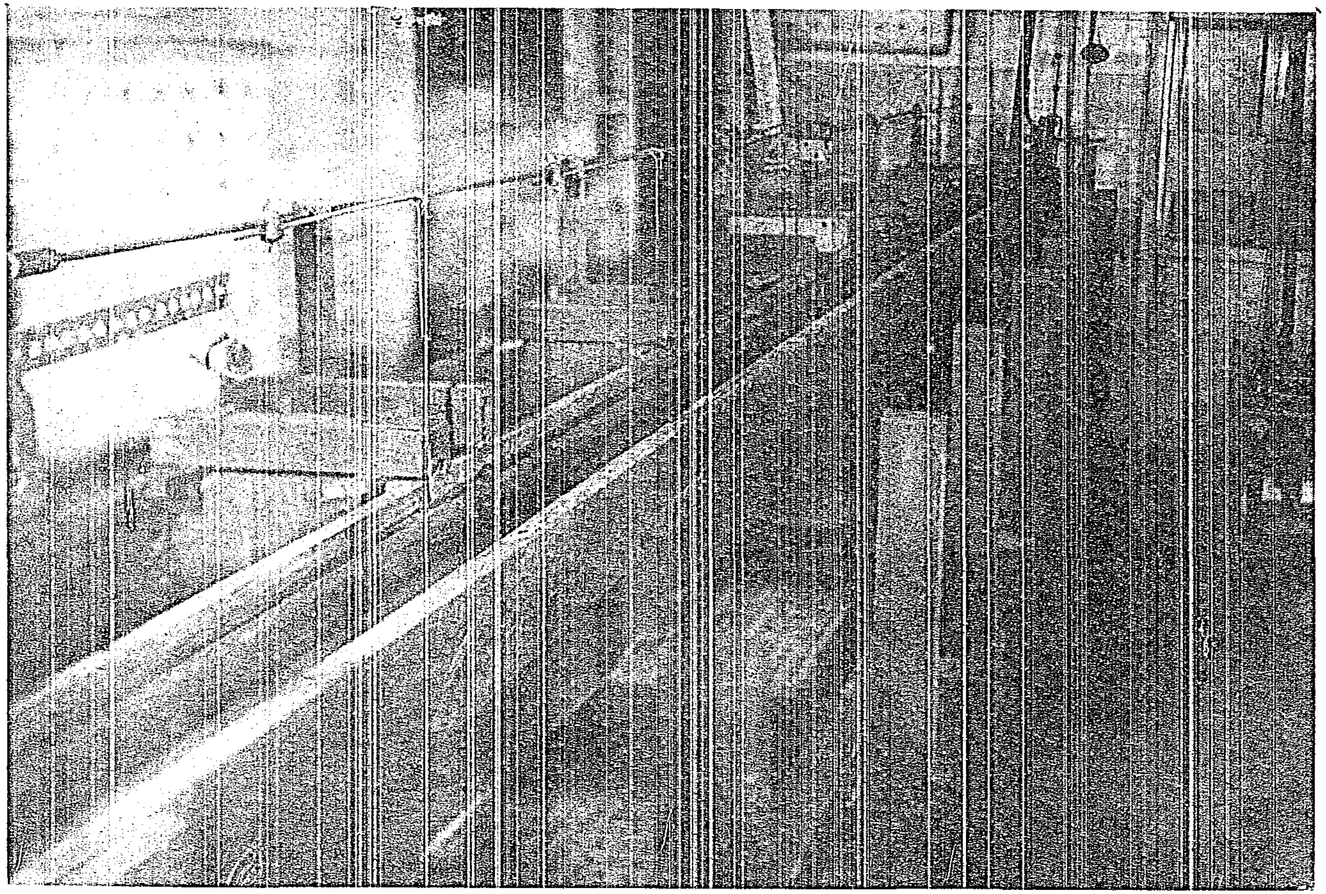


Fig. 12 Top of Filters and Dosing Device from Southeast Corner of Second Floor

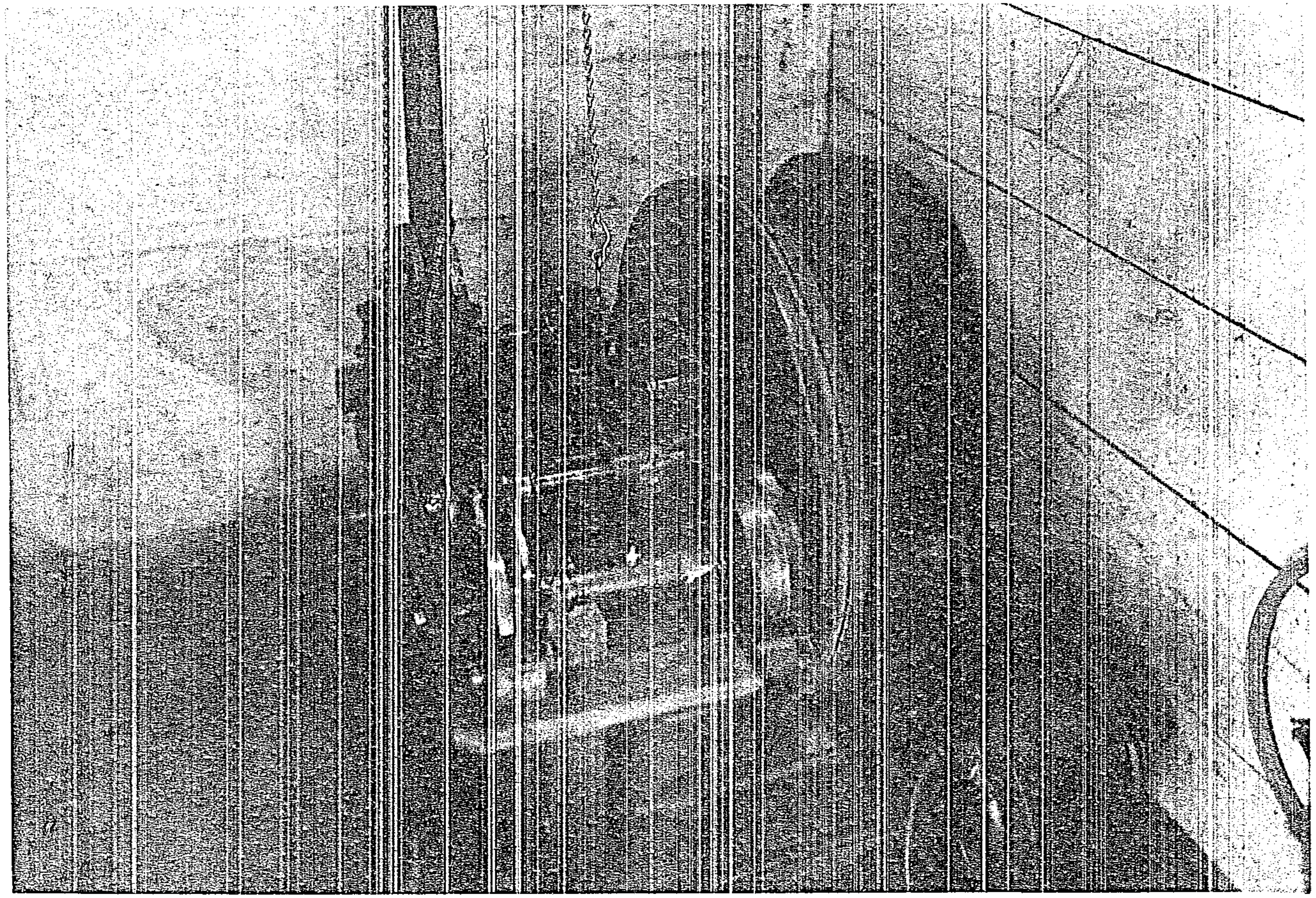


Fig. 13 Motor Driven Pump and Operating Mechanism

Fig. 14 Bottom of Filters Showing Samplers, Sample Buckets and Ventilating Ports.

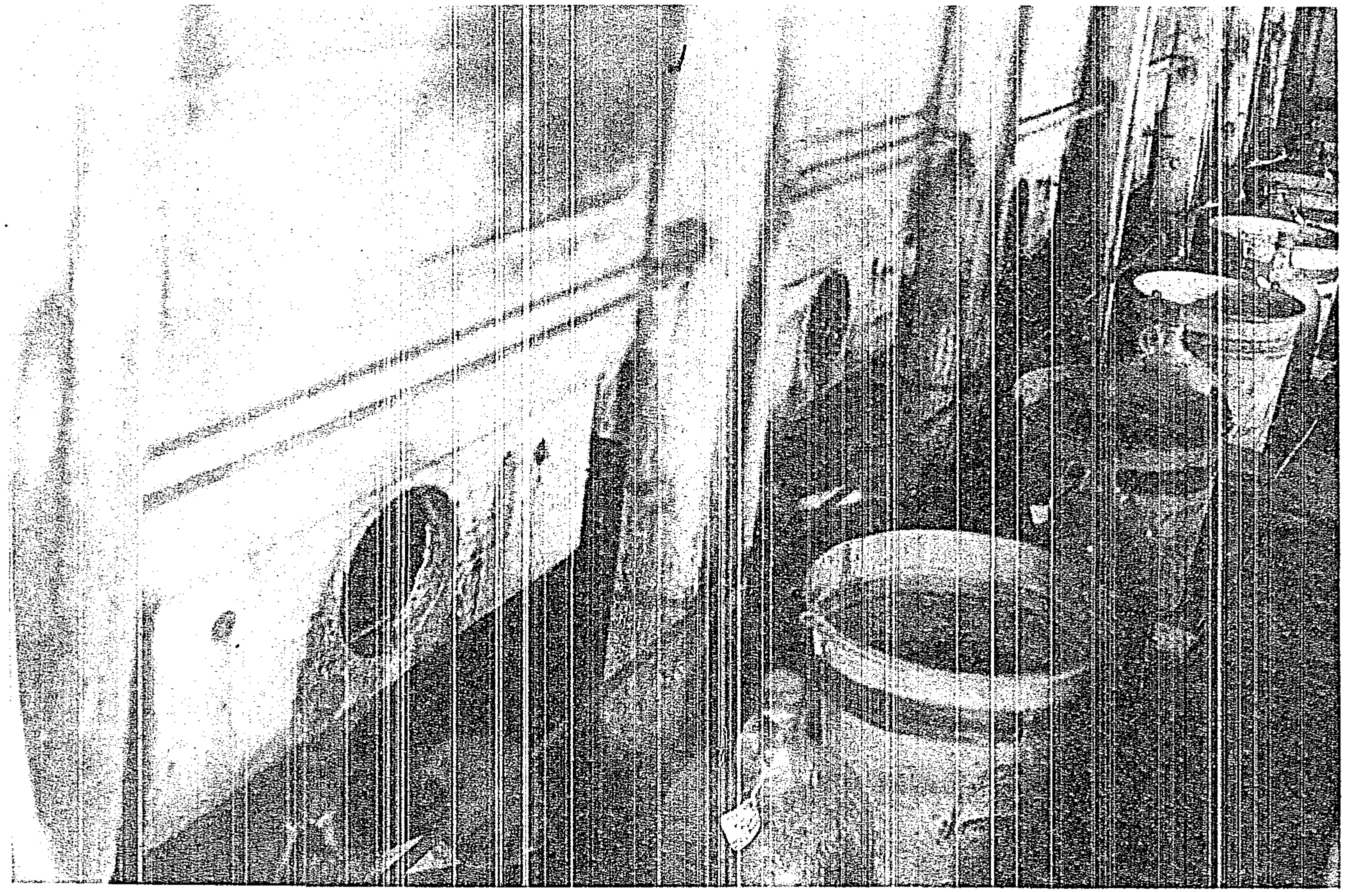


Fig. 15 Side View of Bottom of Filters Showing Samplers and Sample Buckets.

Fig 16 SCHEMATIC DIAGRAM OF EXPERIMENTAL SETUP

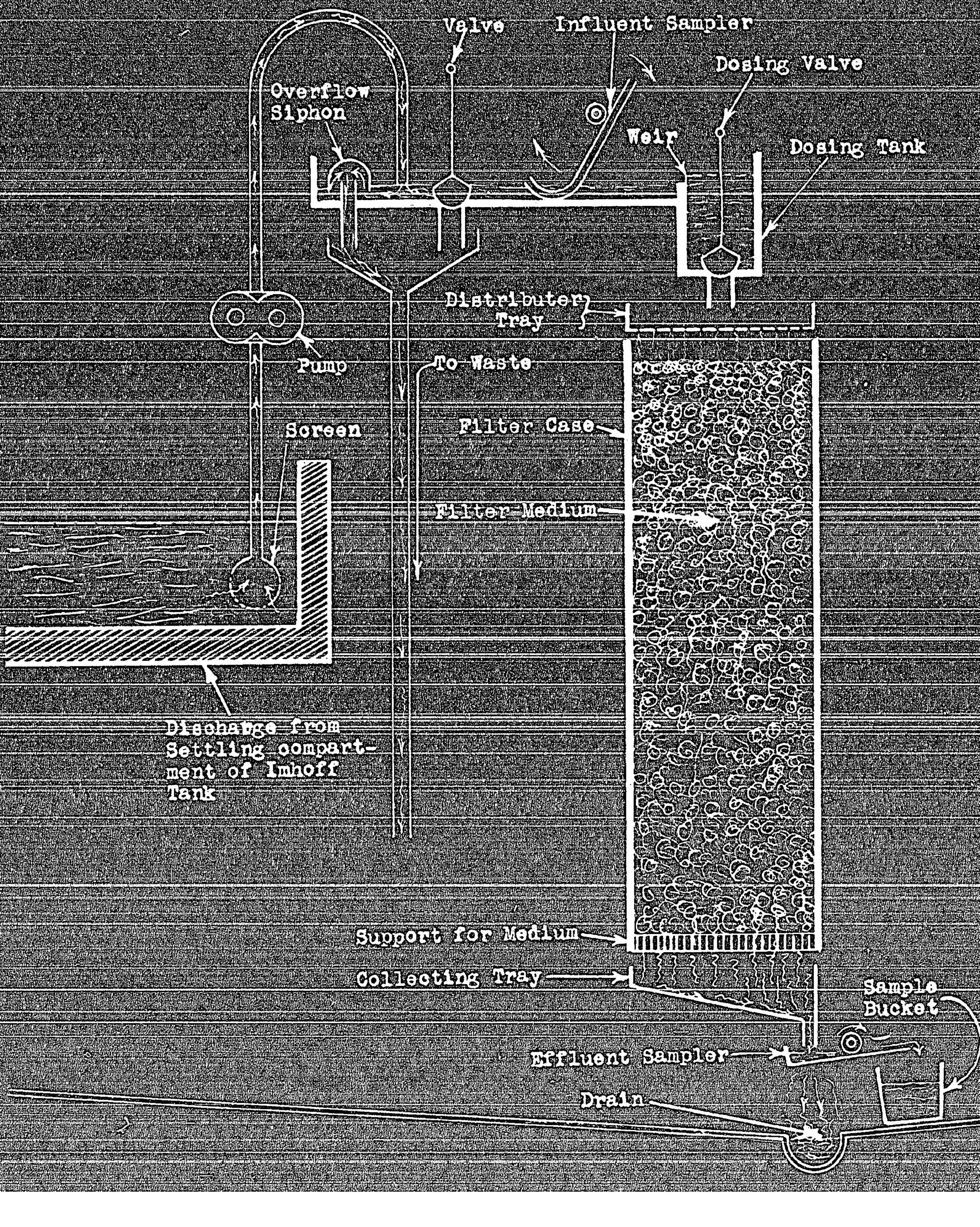
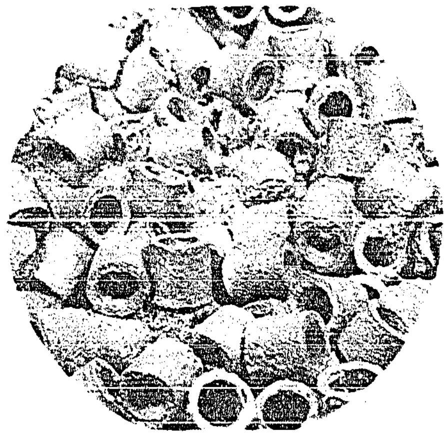
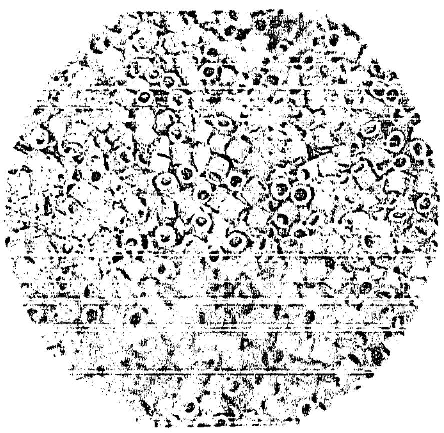


Fig. 17 Filter Media in Filters with Microbial Film Developed

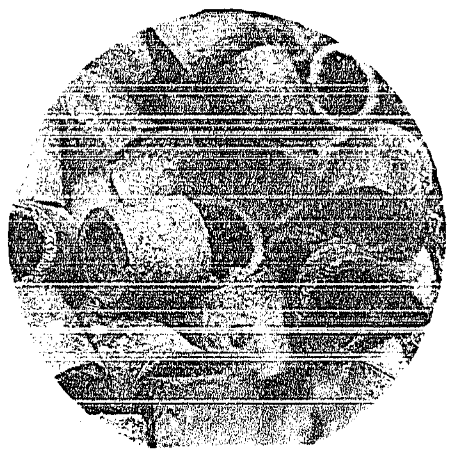
Granite



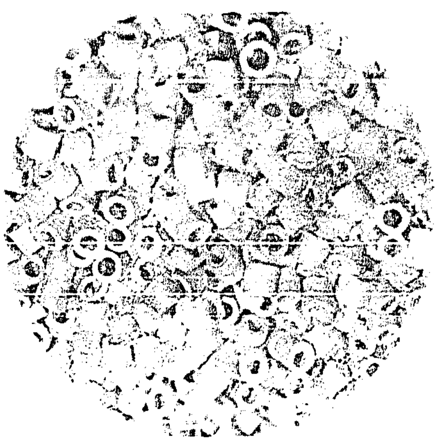
1 1/2-inch Rings



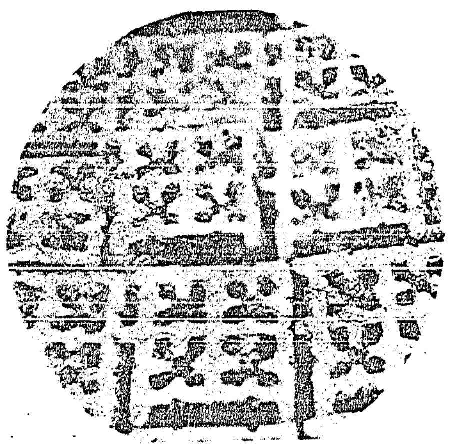
3/4-inch Rings



2 1/4-inch Rings



1-inch Rings



Straight's Block

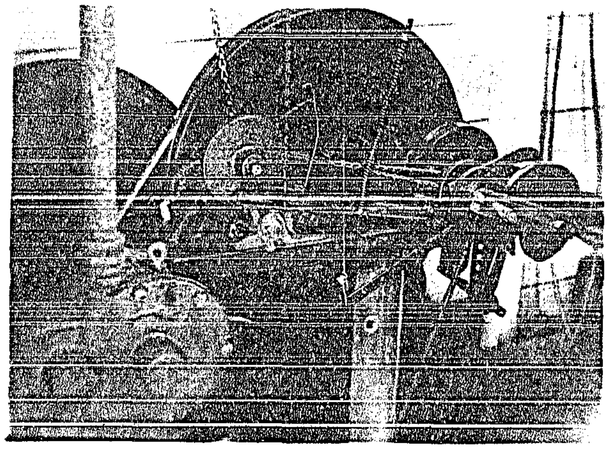


Fig. 18 Side View of Motor Operated Pump and Operating Mechanism.

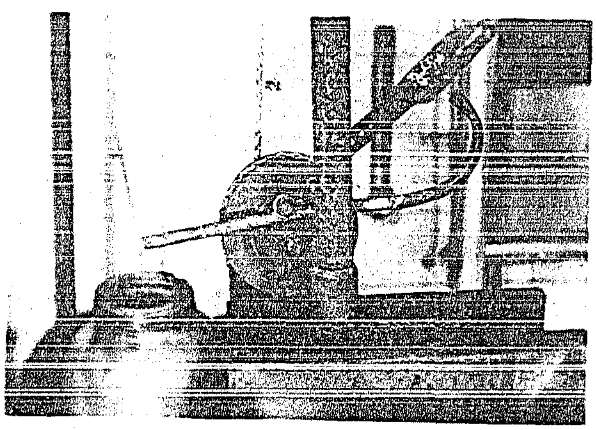


Fig. 19 View of Influent Sampler and Sample Container.

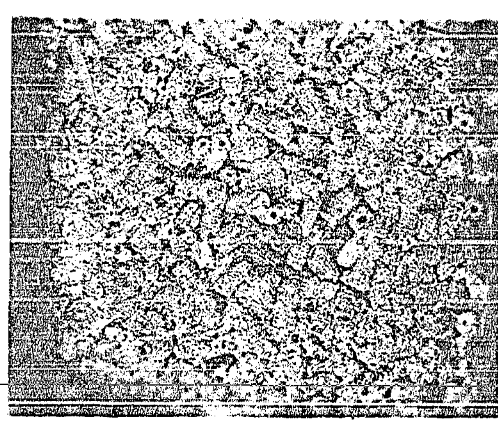


Fig. 20 Top View of Corn Cob Filter with Microbial Film Developed after 9 Months Operation.

valves were used for both the drain and dosing valves. Short sections of 2-inch pipe with the inside ends beveled and the whole copper plated were used as valve seats for the quick opening valves.

The perforated metal distributing trays were about 5 inches below the dosing tank discharge and about 8 inches above the filter medium. Two sets of distributing trays were available--one with the holes spaced on three-inch centers for small doses of waste, and another set with the holes spaced on one-inch centers for larger doses of waste. The distributing trays were not merely plates with holes drilled. Instead, by means of a punching operation a depression was formed around each hole, the depression being nearly spherical, one-half inch in diameter and about three-sixteenths of an inch in depth. These depressions prevented the waste from flowing along the under side of the plate. Stiffner fins were used on the under side of the distributing trays to prevent sagging at the center.

In Fig. 11 and 12 the distributing trays with holes spaced on one-inch centers are to be seen in place on the filters, while other trays with holes on three-inch centers are to be seen hanging on the walls of the building. It should be pointed out that the distributing trays were about 5 inches above the top of the filter case, thus allowing free ventilation at the top of the filter.

The filter medium was supported on a wood grid made up of paraffinned wood lath, on edge, with wood spacers between. The free air space through the grid was over 50 per cent. The effluents from the filters were collected by means of sheet metal cones with the edges about one-inch below the grids supporting the media.

d. Sampling equipment.

Daily composite samples were collected from the influent and each of the effluents. The influent sampler is shown in Fig. 19. The curved copper tube shown in the discharge position in the picture, dipped into the distributing trough at about 2-minute intervals and collected a small sample which was transferred to the glass jug. About one gallon was collected in 24 hours in this manner. In this influent sampler a constant amount was collected on each sample.

The variations in concentration of waste were comparatively slow, and there was little danger of not obtaining a representative sample of suspended solids. In the case of the effluent samples the situation was quite different. The run-off from the filters, just as the application, was cyclic, although not as much so. The hydraulics of this situation will be discussed more in detail under "Hydraulics of Trickling Filters". During the cycle there was a variation in rate of flow, in suspended solids and in concentration of effluent. In order to obtain a composite sample under these conditions it was necessary that the sample represent a constant percentage of the total flow. The small flow from the filters made it impractical to collect a sample continuously. Instead, the total flow from each filter was collected for a small percentage of the total operating time. That is, the sampler was so designed as to catch the total flow from each filter for a fixed time interval during each sampling cycle. The sampling cycle was about, although not exactly, two minutes in length. The sampling cycle was not in synchronism with the dosing cycle. In this manner, all points in the dosing cycle were covered in a few hours. Since the sample included the total flow from the filter, there was neither gain nor loss of suspended solids. In practice the sampler, shown in Fig. 14 and 15 consisted of a sampling thief or spoon which was moved across the filter effluent stream at a constant rate. The sampling thieves were attached to the long shaft directly above the sample buckets. This shaft with the seven thieves was moved back and forth longitudinally by means of the motor driven operating mechanism. In action there were two strokes to a sampling cycle--the sampling stroke and the waste stroke. On the sampling stroke the thief, in Fig. 14 moved from right to left at a constant velocity, and at the end of the stroke the thief was turned up so as to discharge the small sample collected into the bucket. On the waste stroke the thief moved in the opposite direction, but with an intermittent motion given by a rachet drive. Upon reaching the end of the stroke the thief was again turned up and discharged, but the sample collected was wasted. The rate at which the thief moved across the effluent stream during the sampling stroke was controlled by means of a dash-pot arrangement.

In addition to the 24-hour composite samples, bi-weekly chloroformed composite samples were collected. These were obtained by placing 250 cc. of the well-mixed 24-hour composite sample in the glass jugs seen at the bottom of the filters.

3. Analytical Methods.

Unless otherwise stated the procedures given in Standard Methods (2) were followed in all analyses.

Unless otherwise stated the B.O.D., dissolved oxygen, relative stability, and settlability determinations were made upon the 24 hour composite samples. The solids nitrogen, pH and oxygen consumed determinations were made upon the chloroformed, bi-weekly composite samples. The 24-hour composite sample was brought from the plant to the laboratory in quart bottles. The bi-weekly composite sample was collected and brought to the laboratory in one-gallon glass jugs.

Dissolved oxygen content was determined by the Rideal-Stewart modification of the Winkler method. All reagents were added beneath the surface of the liquid by means of narrow tipped burettes. It was found that the use of burettes rather than pipettes both increased the accuracy of addition and also reduced the time necessary.

Biochemical oxygen demand. The dilution method of B.O.D. determination, using aerated distilled water buffered with 300 p.p.m. of sodium bi-carbonate as dilution water, was used throughout the investigation. During the early part of the work the dilutions were made in a litre flask. Starting on March 6, 1935, however, the dilutions were made directly in the B.O.D. bottles. The sample was added by means of a pipette beneath the surface of the dilution water contained in a B.O.D. bottle.

Incubation was 5 days at 20 degrees C., in a water bath, in all cases. In the calculation of B.O.D. correction was made for dissolved oxygen in the sample, if the dilution was 5 per cent or over.

Relative stability was determined according to standard methods, save that rubber stoppered bottles were used. It was found that the use of 150 cc. prescription bottles with rubber stoppers was quite satisfactory when the bottles were incubated in a water bath.

Settlability. The shaken samples were placed in an Imhoff cone of 1 litre capacity. The solids settling out at intervals of 30 minutes, 1 and 2 hours were recorded. In this paper the amount of solids settlings out in 1 hour are reported in terms of cc. per litre of sample.

Oxygen consumed. The procedure outlined in Standard Methods of Water Analysis was followed except that more concentrated potassium permanganate and ammonium oxalate solutions were used. The solutions used were of such concentrations that 1 ml. of solution was equivalent to 1 mg. of oxygen. This concentration of solution was used to reduce the sampling error always present in samples containing suspended solids. This concentration permitted the use of a larger sample than would have been possible had the concentrations suggested by Standard Methods been used.

pH determinations were made by means of a quinhyrdone electrode set. The determinations were made on filtered samples.

Solids determinations were made by evaporating a measured shaken sample to dryness on a hot plate, drying for one hour at 105 degrees C. in a drying oven, cooling and weighing. The weight obtained was considered the dry weight of Total Solids. The residue was then ignited at 700 degrees C. and again weighed. The difference between this and the previous weight was considered the volatile,--Total Solids. The shaken samples filtered through fine filter paper were used for the determination of dissolved solids. The determination was made as for total solids.

Nitrogen determinations with the aid of the Duboscq colorimeter. All nitrogen determinations were made colorimetrically by means of the Duboscq Colorimeter. A method was was worked out for using the Duboscq colorimeter for nitrogen determinations and was used throughout this investigation.

The details of the method and its development are presented here.

The Duboscq colorimeter is commonly used for rapid colorimetric analyses. The ease with which the two half circles of color are matched makes for greater speed and accuracy than when Nessler tubes and a prepared series of standards are used.

In the use of the Duboscq colorimeter for colorimetric analyses two problems are presented. First, it is necessary that equal color concentrations be produced by equal concentrations of the substance being analyzed for, under all conditions; that concentrations of salts apt to be present in the sample will not change or interfere with the color production nor produce cloudiness. Second, it is necessary that either the color production be a known function of the concentration of the substance being analyzed for or that the relationship be empirically determined.

The nitrogen determinations being considered here are free ammonia and nitrite. By reduction, nitrates may be determined as free ammonia. Organic nitrogen may be digested by the Kjeldhall method to ammonia and determined as such.

In the case of the free ammonia determination, the color is commonly produced by Nessler's reagent, which is an alkaline solution of potassium mercuric iodide K_2HgI_4. With ammonium salts a yellow-orange colored complex compound, probably $HgO\ Hg(NH_2)I$, is formed. This colored compound is probably present as colloidally dispersed particles rather than as a true solution. These particles are, however, so finely dispersed as to produce a clear solution. Calcium and magnesium salts and many undetermined organic compounds, on the other hand, react with Nessler's solution to cause cloudiness which interferes with the analysis.

Yoe (33) suggests the addition of Rochelle salt to prevent cloudiness. It was found that the addition of Rochelle salt prevented cloudiness even in very low concentrations, but that the addition of Rochelle salt produced a marked change in color intensity. It appears logical that if Rochelle salt causes a marked change in color intensity, other organic compounds may also cause a similar change. The effect of several organic compounds on the color intensity produced by Nessler's solution and ammonia was investigated. These effects are graphically shown in Fig. 21. The data shown in this figure were obtained as follows: A Nesslerized sample containing 2 p.p.m. of ammonia was placed in one cup of the colorimeter and the depth set at 20 mm. Nesslerized solutions containing various concentrations of organic compounds in addition to the 2 p.p.m. of ammonia were placed in the second cup and the depth adjusted until the color matched with the first cup. The depth at which matching was obtained is shown in Fig. 21 as the colorimeter reading. It will be noted that in most cases the addition of organic compounds changed the color concentration produced. The Rochelle salt and sodium citrate have similar effects. Fortunately both of these salts soon reach what may be termed a maximum effect which continues over a considerable range.

It is probable that most compounds have some effect on the color production, but it is also probable that the effect ordinarily encountered will be less than that of Rochelle salt or sodium citrate. It seems desirable to add Rochelle salt to the sample to be Nesslerized, both to prevent cloudiness and to reduce the interferring action of other compounds. From the curve on Fig. 21 it would seem desirable to add about 2 to 5 grams of Rochelle salt per litre of sample, or about one cc. of a 250 gm. per litre Rochelle salt solution to a 50 cc. sample.

The relationship between the ammonia concentration and the color production was determined empirically, using known concentrations of ammonia. The relationship between a 2 p.p.m. ammonia standard and various concentrations of sample is shown for three depths of the standard solution, on Fig. 22. From this chart it is possible to determine the concentration of ammonia in a sample over a range between 0.3 and 15 p.p.m. using only one standard ammonia solution. 2 p.p.m. ammonia standard was selected as giving a readily matched color and no precipitate.

The procedure used for ammonia determination is: After either clarification or distillation, make sample to 50 cc., add one cc. of 250 gm. per litre of Rochelle salt and one cc. of Nessler's solution and shake. After standing at least ten

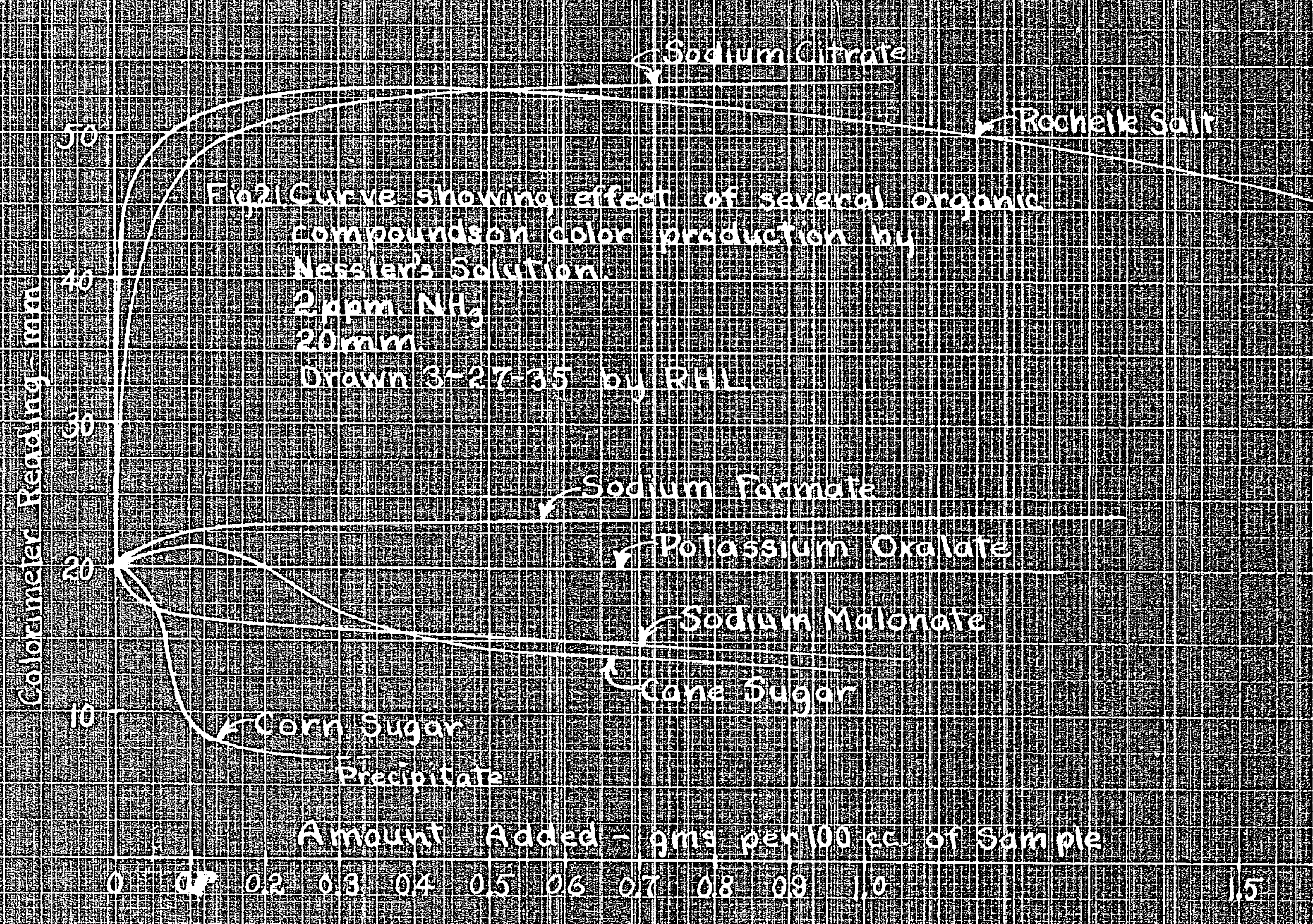


Fig 21 Curve showing effect of several organic compounds on color production by Nessler's Solution.
2 ppm. NH_3
20 mm.
Drawn 3-27-35 by RHL

but not over thirty minutes compare with a 2 p.p.m. ammonia standard similarly prepared, adjusting the depth of the standard solution to exactly 10, 20, or 40 mm. Match colors, observe the depth of sample solution, and read the ammonia concentrations of the sample from the appropriate curve on Fig. 22. As in all colorimetric determinations it is desirable to take a number of readings and use the average as the proper depth. An average of four readings was used in this investigation.

In the colorimetric nitrite determination, color is produced by the interaction of alpha naphthlamine acetate and sulphanilic acid in the presence of nitrous acid. The color is probably a colloidal diazonium compound. No trouble has been experienced with cloudiness. Ordinary substances do not appear to interfere with color formation.

Curves showing the relationship between the color production and nitrite concentration were determined empirically by means of nitrite solutions of known concentration. These curves are shown on Fig. 23. These curves are used in the same manner as those presented for ammonia determination. For the nitrite determination a 0.1 p.p.m. nitrite standard is recommended. This concentration produces a readily matched color and furthermore does not produce a precipitate within thirty minutes.

<u>Nitrogen determinations.</u> Free ammonia samples were prepared by distillation using a phosphate buffer. Organic

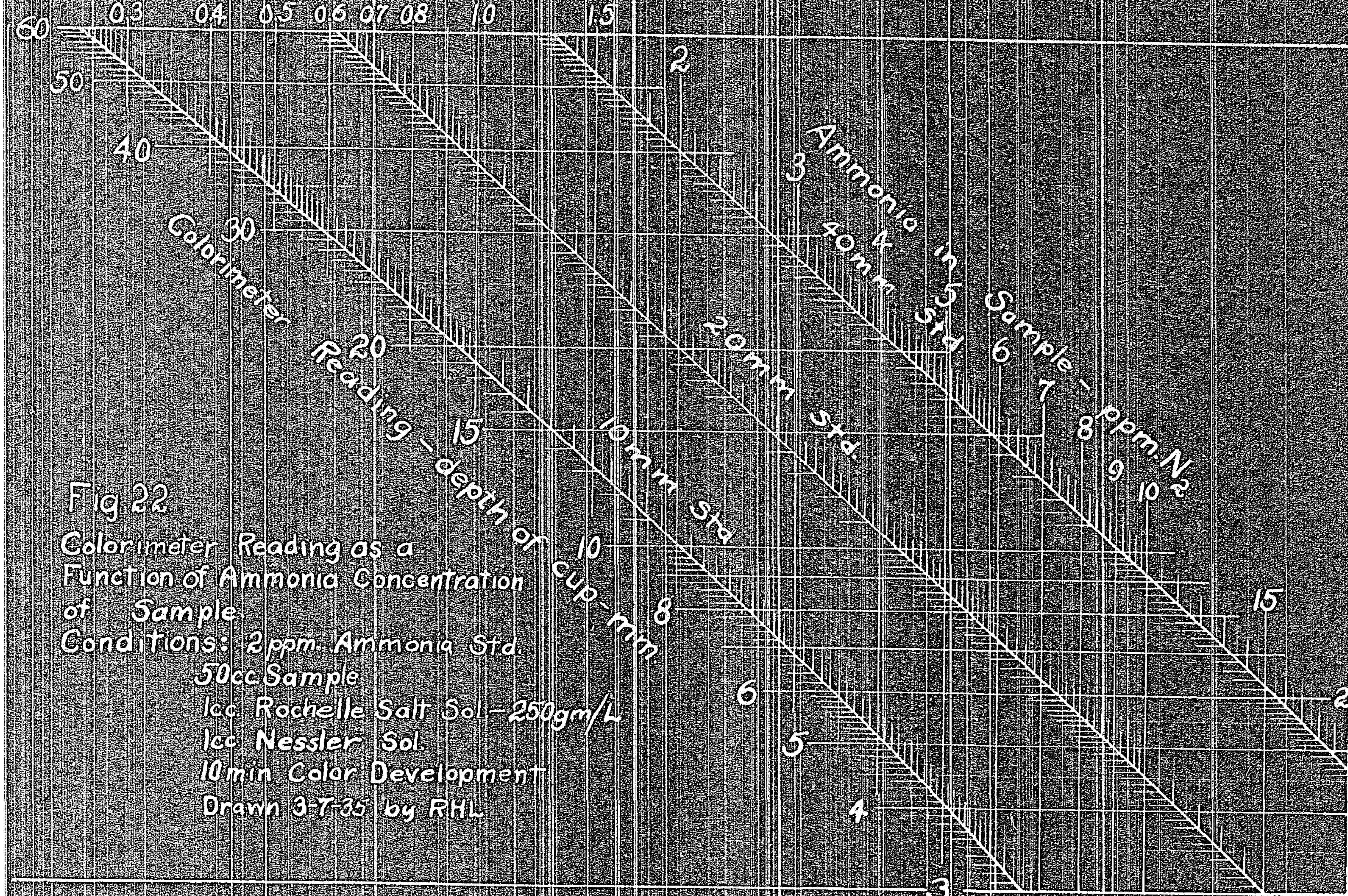


Fig 22
Colorimeter Reading as a
Function of Ammonia Concentration
of Sample.
Conditions: 2ppm. Ammonia Std.
50cc Sample
1cc Rochelle Salt Sol. - 250gm/L
1cc Nessler Sol.
10 min Color Development
Drawn 3-7-35 by RHL

nitrogen determinations were made by the Kjeldhahl method, using copper sulphate as a catalyst. Nitrates were determined by the reduction method, using metallic aluminum in an alkaline solution as a reducing agent.

Filtered samples were used for the nitrite and nitrate determination whereas a well shaken sample was used for the free ammonia and organic nitrogen determinations.

4. Method of Operation and Results.

The operation of the experimental trickling filter plant may be divided into three operating periods, on the basis of the dosage during each of the periods. During the first operating period from August 16, 1934, until December 9, 1934, the filters were dosed at the rate of 2 M.G.A.D. with a dosing cycle of 6 minutes. The plant was operated intermittently for a short period of time before the first operating period, while run-off rate studies were being made, but no samples were taken during this time.

As is to be expected in any experimental setup as intricate as that used in this investigation, mechanical difficulties arose, but most of the difficulties were overcome during the early part of the first operating period. During the second operating period from December 10, 1934, to April 1, 1935, the waste was applied at the rate of 4 M.G.A.D. with a 3 minute dosing cycle. During this period some ir-

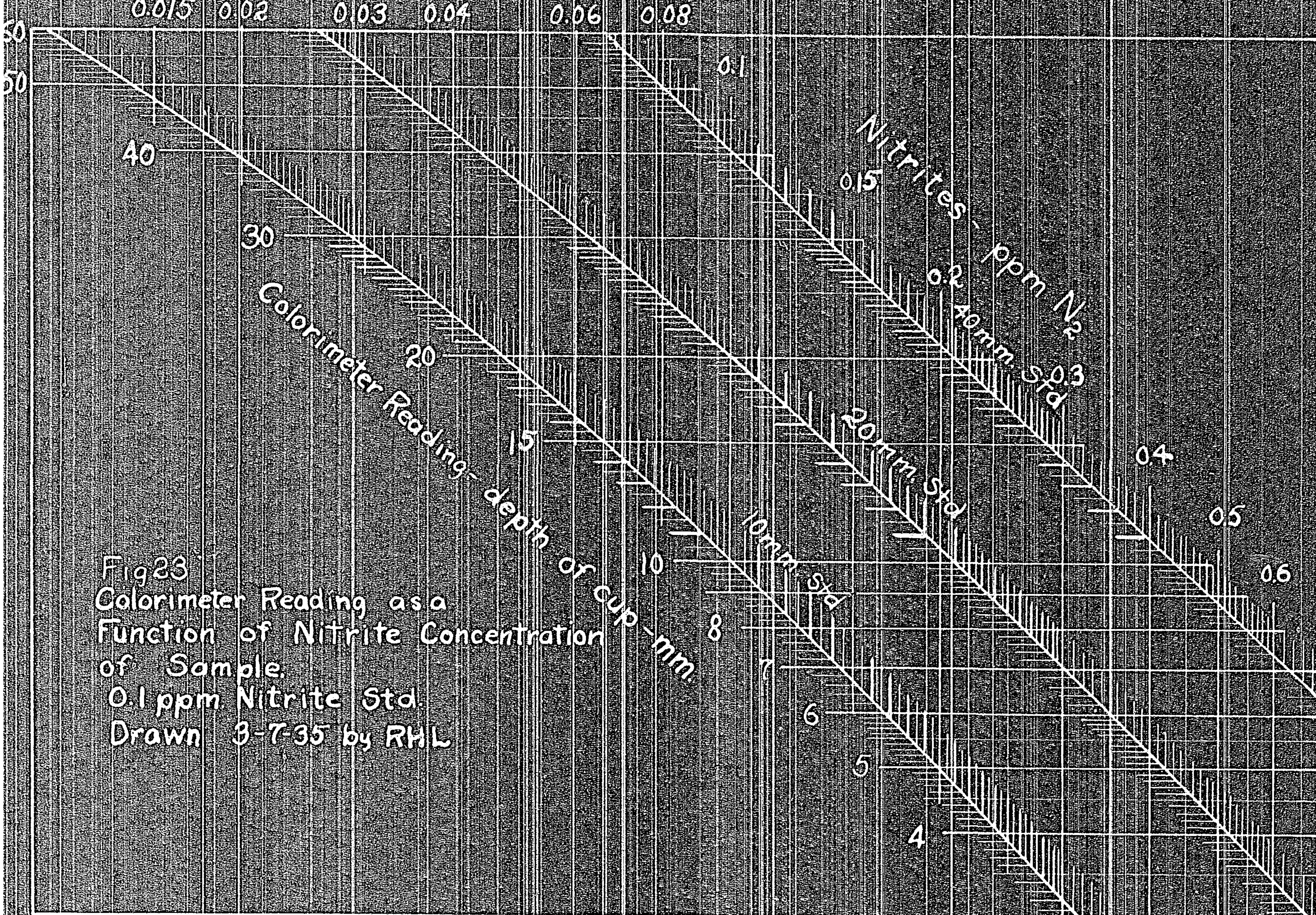


Fig 23
Colorimeter Reading as a Function of Nitrite Concentration of Sample.
0.1 ppm. Nitrite Std.
Drawn 3-7-35 by RHL

regularity of operation was caused by the extreme cold weather. Gas produced by sludge digestion in the city plant was used to heat the building housing the experimental plant. However, the high moisture content of the sludge gas frequently collected in the gas line and caused stoppage. These interruptions in gas flow, in part, account for the variations in room temperature. The extreme cold, together with an inability to get gas and sewage continuously made it necessary to discontinue the operation of the experimental plant for the period January 20 to February 14. In a large plant the cold weather would not have presented a serious difficulty. The temperature of the incoming sewage is always warm enough to keep the filters from freezing, provided the dosing cycle does not become too long during the low night flow.

During the third operating period from April 2 until June 18, 1935, the waste was applied at the rate of 8 M.G.A.D. with a 3 minute dosing cycle. The experimental plant operated very uniformly during this period. However, because of spring rains the sewage applied was at times quite dilute. In fact the plant was shut down at the end of the period because of extreme high water which rose into the pump house well, and caused pumpage of part river water.

After the river subsided the plant was again put into operation with a rate of application of 16 M.G.A.D. and a 3-minute dosing cycle. This rate is being continued and will be reported elsewhere.

The question has been raised as to whether the waste applied to the filters at any given dose might not vary as a result of hydraulic separation in the distributing trough.

The possibility of a significant variation in concentration of sewage applied to each of the filters simultaneously, caused by selective action, distance from pump, etc., was investigated. The distributor trays were removed and a collecting pan placed beneath each dosing valve. With the dosing device operating normally (3 min. cycle, 4 M.G.A.D., March 9th) one dose was collected from the seven filters, and simultaneously one grab sample from the distributing trough. These samples are numbered from 1 to 8, No. 8 being the grab sample. Five B.O.D. determinations were made on each of these eight samples. The data obtained in this manner together with the necessary calculations (30) follow:

Concentration of Sewage Applied to Experimental Filters as Measured in Terms of B.O.D. in ppm.

Samples	Analyses					Sum	Mean	Sum of Squares
	1	2	3	4	5			
1	302	190	190	195	180	1057	211.4	233828
2	217	190	205	200	190	1002	200.4	201514
3	200	197	195	210	187	989	197.8	195903
4	402	185	187	190	192	1156	231.2	303762
5	202	207	207	227	207	1050	210.	220880
6	207	272	195	192	197	1063	212.6	230551
7	217	217	207	412	207	1260	252.	349620
8	170	185	210	190	175	930	186.	173950
Sum	1917	1643	1596	1816	1535	8507		
Mean	239.6	205.8	199.5	227	191.9		212.6	
Sum of Squares	499539	343381	318942	452462	295465			1909789

First, the correction term is calculated:

$$\text{Correction term} = \frac{(8507)^2}{40} = 1{,}809{,}438.9$$

Second, the total sum of squares is given by:

$$1909{,}789 - 1{,}809{,}438.9 = 100{,}350.1$$

Third, the sum of squares between means of analyses is:

$$\underline{(1057)^2 + (1643)^2 + (1596)^2 + (1816)^2 + (1535)^2} - 1{,}809{,}438.9$$

$$= 12{,}515.5$$

Fourth, the sum of squares between means of samples is:

$$\frac{(1057)^2 + (1002)^2 + (989)^2 + (1156)^2 + (1050)^2 + (1063)^2 +}{5}$$

$$\frac{(1260)^2 + (930)^2}{5} - 1{,}809{,}438.9 = 12{,}167.3$$

Fifth, the remainder:

$$100{,}350.1 - (12{,}515.5 + 12{,}167.3) = 75{,}667.3$$

Analysis of Variance of Concentration of Sewage Applied to Experimental Filters

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square
Total	39	100,350.1	
Between means of analyses	4	12,515.5	3128.9
Between means of samples	7	12,167.3	1738.2
Remainder, interaction	28	75,667.3	2702.4

The chief objective of this investigation is to test the significance of the mean square between samples. Hence the ratio,

$$F = 3128.9/1738.2 = 1.8$$

is compared with the tabular values 4.12 and 7.85 given as significant for 4 and 7 degrees of freedom. The conclusion is that the differences among sample means are not significant, but may be explained by the random variation of sampling and B.O.D. determination.

The B.O.D. values of the influent and the effluents from each of the seven filters for both shaken and settled samples, for each of the three operating periods are given in Tables No. 4, 5, and 6.

The dissolved oxygen content of the filter effluents during the three operating periods are given in Table No. 7. The analyses of dissolved oxygen content were made on the 24 hour composite sample in every case. A grab sample would probably have given a slightly different value.

The relative stability values of the filter effluents during the three operating periods are given in Tables No. 8, 9, and 10.

The settlable solids in terms of cubic centimeters of solids per litre of sample upon one hour settling for the three operating periods are given in Table No. 11. The settlable solids determination was not made before Nov. 23. The test was made by means of standard Imhoff cones.

Daily room and influent temperatures for each of the three operating periods are given in Tables No. 12, 13, and 14.

<u>Bi-weekly composite samples.</u> The information gained from the bi-weekly composite samples is given in Tables No. 15, 16, and 17. These tables include the nitrogen, oxygen consumed, pH, and solids determinations, together with some general notes on the plant operation during each compositing period.

<u>Summary.</u> Table 1[illegible] contains a summary of all operating data. The values given are averages for all determinations. In the case of the determinations made on the 24-hour composite samples, the values given are an average of all determinations made during the given operating period. In the case of the determinations made on the bi-weekly composite samples, the values given are an average of all the bi-weekly composite values for the given operating period.

The data presented in these tables will be discussed more in detail under "Discussion of Results".

4	218	60	33	42	65	[illegible]	[illegible]	[illegible]
5	193	39	14	28	59	60	49	61
8	135	57	19	38	61	60	51	75
10	217	50*	14	29	61	65	53	97
12	212	45	38	54	60	63	45	87
15	210	64	62	32	64*	65	64*	136
17	230	56	50	71	70*	72*	67	112
18	230	33	29	46	60	58	40	86
19	175	53	23	42	67	59	52	85
22	175	52	66	58	62	60	62	56
24	192	46	47	51	59	58	66	59
25	255	51	59	55	56	58	63	85
26	260	54	59	54	64	65	65	82
29	227	64	71	67	67	67	67	70
31	330	66	41	56	67	60	54	76
Nov. 1	207	65	49	50	67	65	69	83
5	232	60	32	61	62	62	62	76
7	177	52	33	50	63	65	-	49
8	257	66	26	53	59	58	67	91
9	297	68	46	62	65	74	80*	92
12	175	67	32	41	49	72	72	90
14	122	44	16	18	49	49	50	59
19	220	70	38	40	70*	68	78	121
23	180	76	50	63	72	75	70	110
28	207	70	64	67	63	75	67	116
Dec. 5	152	62	26	45	61	65	67	108
7	140	68	25	53	71	74	-	103
No. of Analyses	37	37	37	37	36	37	35	37
Average	186.3	55.5	35.4	45.6	59.7	60.7	58.6	86.2
Std. Dev.	68.7	15.1	16.4	13.8	10.9	13.0	13.6	22.6
Average Reduction	-	71.3	82.6	77.2	69.3	67.9	70.4	55.8

(*) Dilution completely depleted. Value shown is that of 100% depletion.
(-) Analysis not complete
(g) Grab sample, 2 cycles
Note: Shaken samples were used for all determinations of influent samples.

29	227	30	16	26	35	31	27	31
31	330	22	7	10	18	20	12	30
Nov. 1	207	35	16	18	33	30	15	27
5	232	23	13	22	21	25	20	37
7	177	20	7	14	20	19	8	41
8	257	20	4	9	10	10	7	40
9	297	36*	16	27	29	36	40*	41
12	175	19	11	8	16	22	14	40
14	122	14	6	6	15	25	15	42
19	220	16	5	8	29	26	22	93
23	180	38	15	20	35	33	32	62
28	207	36	25	35	30	34	34	70
Dec. 5	152	32	12	17	26	28	21	72
7	140	37*	9	12	24	26	28	32
No. of Analyses	40	40	40	39	38	39	39	39
Average	193.9	24.0	12.0	16.8	24.9	22.8	21.2	53.8
Std. Dev.	50.2	10.9	8.3	10.0	9.4	9.5	12.8	26.1
Average Reduction	-	87.3	93.7	91.2	86.9	87.8	86.4	69.9

Date				B.O.D. of Shaken Samples - ppm.				
Sample	Inf.	1	2	3	4	5	6	7
Sept. 14	160	40	18	31	-	25	28	105
20	176	57	22	35*	32*	35*	34*	98
22	223	33*	21	32	33*	32*	32*	133*
24	173	30*	15*	15*	26*	30*	30*	92
26	152	48	27	48	64	66	65	104
27	250	65	35	43	54	64	70*	76
28	218	64	40	52	68	72	72*	73
29	185	63	32	45	63	69*	70*	60
Oct. 1	145	57	25	38	71*	65	63	55
3	135	38	13	21	45	52	52	50
4	218	60	33	42	65	65	55	77
5	193	39	14	28	59	60	49	61
8	135	57	19	38	61	60	51	75
10	217	50*	14	29	61	65	53	97
12	212	45	38	54	60	63	45	87
15	210	64	62	32	64*	65	64*	136
17	230	56	50	71	70*	72*	67	112
18	230	33	29	46	60	58	40	86
19	175	53	23	42	67	59	52	85
22	175	52	66	58	62	60	62	56
24	192	46	47	51	59	58	66	59
25	255	51	59	55	56	58	63	85
26	260	54	59	54	64	65	65	82
29	227	64	71	67	67	67	67	70
31	330	66	41	56	67	60	54	76
Nov. 1	207	65	49	50	67	65	69	83
5	232	60	32	61	62	62	62	76
7	177	52	33	50	63	65	-	49
8	257	66	26	53	59	58	67	91
9	297	68	46	62	65	74	80*	92
12	175	67	32	41	49	72	72	90
14	122	44	16	18	49	49	50	59
19	220	70	38	40	70*	68	78	121
23	180	76	50	63	72	75	70	110

Table No. (4) B.O.D. Data Obtained During First Period: 2 M.G.A.D., 6 Min. Cycle

Date	B.O.D. of Settled Samples - ppm.							
Sample	Inf.	1	2	3	4	5	6	7
Aug. 25	265	27	12	21	21	12	17	105
31	160	28	23	25	19	52	56	99
Sept. 1	165	16	41	64	29	11	37	48
3	102	10	5	6	6	11	9	53
4	160	24	8	12	12	13	10	82
5	205	39	11	19	32	42	30	125
6	120	8	6	12	51	16	61	103
(g) 6	160	50	5	6	41	20	16	37
7	166	17	6	-	-	-	-	-
10	186	47	18	16	35	25	33	60
11	212	16	5	31*	21	15	17	55
12	205	27	12	24	30*	29	29	65
14	130	11	9	13	24	18	4	93
17	114	6	4	5	7	5	3	17
Oct. 5	193	8	6	7	25	27*	9	16
8	135	15	3	6	13	24	12	50
10	217	32*	7	12	34	33*	27	65*
12	212	11	5	10	26	15	5	19*
15	210	30	30	15	29	21	30*	57*
17	230	22	11	30	29	20	24	66*
18	230	12	2	8	-	20	15	60*
19	175	30	11	18	31	26	17	60*
22	175	17	14	8	19	12	11	31
24	192	25	20	12	16	14	15	24
25	255	24	25	23	30	19	16	36
26	260	31	21	20	25	23	20	35
29	227	30	16	26	35	31	27	31
31	330	22	7	10	18	20	12	30
Nov. 1	207	35	16	18	33	30	15	27
5	232	23	13	22	21	25	20	37
7	177	20	7	14	20	19	8	41
8	257	20	4	9	10	10	7	40
9	297	36*	16	27	29	36	40*	41
12	175	19	11	8	16	22	14	40
14	122	14	6	6	15	25	15	42
19	220	16	5	8	29	26	22	93
23	180	38	15	20	35	33	32	62
28	207	36	25	35	30	34	34	70
Dec. 5	152	32	12	17	26	28	21	72
7	140	37*	9	12	24	26	28	32
No. of Analyses	40	40	40	39	38	39	39	39
Average	193.9	24.0	12.0	16.8	24.9	22.8	21.2	53.8
Std. Dev.	50.2	10.9	8.3	10.0	9.4	9.5	12.8	26.1
Average Reduction	-	87.3	93.7	91.2	86.9	87.8	88.4	69.9

20	227	73	73	83	122	141*	11[illegible]	11[illegible]
22	212	69*	50	66	71*	72*	72*	71*
25	157	71.5	28	44.5	71.5	72.5	63	134
27	225	74*	32	63	74*	75*	76	122
March 1	212	71*	27	21	44	75*	45	115
4	135	58	30.5	36	27.5	57	61.5	83
8	167	31	18	13	11.5	65.5	39.5	80*
11	120	60	19	12	27	46	26	75*
13	202	77*	27	24	77*	77*	61.5	77*
18	218	64.5	35	29	40	70	66	160
25	220	12	16	17	16	[illegible]	2	78
27	160	47	38	35	50	43	20	120
April 1	180	32	37.5	55	57	2[illegible]	16	94
Number of Analyses	21	21	21	21	21	21	21	21
Average	184.4	53.2	34.4	41.8	47.9	56.4	51.2	92.2
Average Reduction		71.1	81.4	77.3	[illegible]	69.4	[illegible]	50.0

B.O.D. of Shaken Samples - p.p.m.

Dec. 12	185	68	86	122	92	120	129	139
14	172	120	78	41	105	76	134	147
17	225	112	53	56	56	72	82	127
21	107	149*	36	72	74	125	107	186
28	140	65	53	83	60	[illegible]	72	142
31	115	81	56	67	50	73	81	116
Feb. 14	215	99	75	79	109	127	76	80
18	225	123	51	70	105	139*	138*	65
20	277	99	81	96	144*	148*	151*	148*
22	212	146*	60	83	136	148*	143	133
25	157	116	35	59	96	130	85	145
27	225	149	36	89	119	159*	114	163*
March 1	212	108	81	93	149*	155	73	160*
4	135	83	95	95	64	96	80	165
8	167	53	76	84	59	105	101	167
11	120	134	42	70	58	123	10[illegible]	158*
13	202	162*	45	62	162*	162*	154	162*
18	218	160	75	83*	156	161	168	192
25	220	425	130	136	173*	159	160	143
27	160	122	127	129	147*	146*	113	132
April 1	180	157*	36	87	137	148	145	145
Number of Analyses	21	21	21	21	21	21	21	21
Average	184.4	129.9	66.3	83.5	107.1	125.2	114.6	141.9
Average Reduction		29.5	64.0	54.7	41.9	32.0	37.8	23.0

(*) Dilution completely depleted. Value shown is that of 100% depletion.

Note: Shaken samples were used for all determinations of influent samples.

Table No. 5 B.O.D. Data Obtained During Second Period.
4 M.G.A.D., 3 min. cycle.

Date		INFLUENT Raw Sewage	FILTER EFFLUENTS Granite	Raschig Rings $\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Stra[illegible] Block	Corn Cobs
B.O.D. of Settled Samples - p.p.m.									
Dec.	12	185	52	36	53	53	35	43	73
	14	172	31	30	34	19	21	67	69
	17	225	63	31	34	25	19	24	70*
	21	107	32	51	39	27	29	70	140*
	29	142	24	39	65	31	37	38	160*
	31	115	7	13	42	14	18	28	77
Feb.	14	215	84	60	69	81	116	65	71
	18	225	68	35	55	75	95	54	56
	20	227	73	75	63	122	141*	117	116
	22	212	69*	50	68	71*	72*	72*	71*
	25	157	71.5	28	44.5	71.5	72.5	63	134
	27	225	74*	32	62	74*	75*	76	122
March	1	212	71*	27	21	44	75*	45	115
	4	135	58	30.5	36	27.5	57	61.5	65
	8	167	31	13	13	11.5	65.5	37.[illegible]	50*
	11	120	67	13	12	27	46	28	75*
	13	202	77*	27	24	77*	77*	61.5	77*
	18	218	64.5	33	29	40	70	65	160
	25	220	12	15	17	10	5	2	78
	27	160	47	38	35	50	45	20	120
April	1	180	32	37.[illegible]	55	57	2[illegible]	16	94
Number of Analyses		21	21	21	21	21	21	21	21
Average		184.4	53.2	34.[illegible]	41.8	47.9	56.4	51.2	92.[illegible]
Average Reduction			71.1	81.4	77.3	74.0	69.4	72.2	50.[illegible]
B.O.D. of Shaken Samples - p.p.m.									
Dec.	12	185	66	86	122	92	120	129	139
	14	172	120	78	41	105	76	134	147
	17	225	112	33	56	56	72	82	127
	21	107	149*	35	72	74	125	107	186
	29	140	66	59	80	60	77	72	142
	31	115	81	56	87	50	75	81	116
Feb.	14	215	93	75	79	109	127	76	80
	18	225	125	51	70	105	138*	138*	65
	20	277	99	81	96	144*	146*	151*	148*
	22	212	146*	60	83	136	148*	145	159
	25	157	115	35	59	95	130	85	145
	27	225	149	36	69	119	159*	114	163*
March	1	212	108	81	93	149*	135	73	130*
	4	135	83	95	96	64	96	80	135

17	260	72*	72*	72*	72*	72*	62
20	100	33	32	25	38	36	41
22	210	56	65	41	55	45	73
29	165	35	12	14	5	30	25
June 3	84	24	13	21	23	23	17
5	175	20	6	9	13	15	10
7	120	20	15	17	22	24	29
10	105	22	17	13	25	19	24
12	160	28	18	16	27	13	21
17	120	24	23	17	20	20	27
Number of Analyses	24	24	24	24	24	24	24
Average	189	46.3	38.9	38.3	41.0	30.7	32.5
Average Reduction		75.2	79.4	79.7	78.3	85.8	79.1

B.O.D. of Shaken Samples - p.p.m.

April 3	205	136	134	141	140	140	140
8	145	134	150	150	149	135	148
10	255	150	158	158	158	148	158
12	150	151	146	155	138	128	151
17	185	102	132	105	76	86	98
19	190	96	115	98	80	90	92
22	260	51	85	71	50	62	61
24	[illegible]	[illegible]	98	109	113	110	121
26	160	65	62	82	78	93	73
29	260	60	51	55	52	70	88
May 1	260	96	77	97	106	100	102
6	205	137	136	139	138	128	142
8	280	93	111	125	94	94	113
13	290	96	135	125	92	79	112
17	260	144*	144*	144*	114*	144*	144*
20	100	77	94	77	68	77	107
22	210	100	133	128	84	124	128
29	165	76	77	110	77	81	100
June 3	85	113	77	103	83	101	74
5	175	78	45	84	69	68	68
7	120	104	42	58	57	89	74
10	105	124	70	88	91	119	95
12	160	86	64	105	71	59	82
17	120	58	42	37	37	56	87
Number of Analyses	24	24	24	24	24	24	24
Average	189	106	100	106	93.7	99.8	106
Average Reduction		43.9	47.1	43.9	50.4	47.2	43.9

(*) Dilution completely depleted. Value shown is that of 100% depletion.
(-) Analysis not complete.

Note: Shaken samples were used for all determinations of influent samples.

Table No. 6 B.O.D. Data Obtained During Third Period.
8 M.G.A.D., 3 min. cycle.

Date	INFLUENT	FILTER EFFLUENTS					
	Raw Sewage	Granite	Raschig Rings $\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Straight's Block
B.O.D. of Settled Samples - p.p.m.							
April 3	205	65	58	64	64	61	47
8	145	56	67	72	68	49	66
10	255	78*	78*	78*	78*	78*	67
12	150	90	73	73	73	32	54
17	185	80	63	45	48	29	16
19	190	62	35	31	40	19	15
22	260	22	21	9	9	6	11
24	190	62	38	46	59	14	25
26	160	43	8	26	37	8	20
29	260	51	34	37	30	12	14
May 1	260	43	24	30	51	28	12
6	205	75*	75*	75*	75*	50	51
8	280	32	39	46	41	27	15
13	290	31	48	42	32	27	37
17	260	72*	72*	72*	72*	72*	62
20	100	33	32	25	36	36	41
22	210	56	65	41	55	45	73
29	165	35	12	14	5	30	25
June 3	84	24	13	21	23	23	17
5	175	20	6	9	13	15	10
7	120	20	15	17	22	24	29
10	105	22	17	13	25	19	24
12	160	28	18	16	27	13	21
17	120	24	23	17	20	20	27
Number of Analyses	24	24	24	24	24	24	24
Average	189	46.8	38.9	38.3	41.0	30.7	32.5
Average Reduction		75.2	79.4	79.7	78.3	85.8	79.1
B.O.D. of Shaken Samples - p.p.m.							
April 3	205	136	134	141	140	140	140
8	145	134	150	150	149	135	148
10	255	150	158	158	158	148	158
12	150	151	146	155	138	128	151
17	185	102	132	105	76	86	98
19	190	96	115	98	80	90	92
22	260	51	85	71	50	62	61
24	190	88	98	109	113	110	121
26	160	65	62	82	78	93	73
29	260	60	51	55	52	70	88
May 1	260	96	77	97	106	109	102
6	205	137	136	139	138	128	142

22	0	1.00	0.75	tr.	tr.	0.40	0
23	0.90	7.20	3.95	1.25	1.20	2.70	tr.
27	0.45	6.90	3.60	2.35	1.90	4.20	2.80
March 1	0	1.20	0.75	0	0	1.10	0
4	0	3.00	2.90	2.30	0	0.25	0
8	2.65	5.00	4.50	3.45	0.45	0.55	0
11	0	4.00	3.35	3.65	0.25	3.40	0
13	0	2.50	3.35	0	0	0	0
15	0	2.40	1.90	0.95	0	0	0
18	0	3.90	3.50	1.85	0.05	1.20	0
25	0	2.50	2.60	2.35	0.85	1.20	0
27	0.90	2.80	2.35	2.30	0.90	3.25	0
April 1	2.95	4.40	3.05	3.85	1.80	3.40	0
Number of Analyses	24	24	24	24	24	24	24
Average	1.42	3.47	2.76	1.94	0.55	1.68	0.27

Third Operating Period - 8 M.G.A.D., 3 min. Cycle.

April 3	2.55	4.70	2.60	1.75	0	1.80
5	0.90	2.70	2.05	1.10	0.65	0.50
10	0.80	1.75	1.25	1.0	0	0.45
12	0.45	1.85	1.95	1.75	0.50	0
17	0	0.50	0.50	0.30	0.35	0.45
19	0	0.70	0.40	0.70	0	0.35
22	0.50	0.60	1.40	1.25	0.45	0.55
24	0.20	1.15	2.55	1.95	1.35	0.8
26	0	1.20	1.50	0.70	0.50	0
29	2.30	3.15	3.90	3.45	2.60	2.45
May 1	1.90	1.20	1.50	1.40	0.70	0.30
6	0.30	0.65	1.35	1.65	1.20	1.45
8	0.90	1.05	2.90	1.50	0	2.20
13	2.45	3.00	3.00	2.25	2.00	0.5
17	0	0.15	0.75	2.35	0	1.05
20	1.90	2.30	2.55	3.60	1.60	2.20
29	0	1.65	2.80	2.40	0.55	2.00
June 3	2.10	3.40	2.80	3.25	1.00	1.55
5	5.15	6.65	5.90	6.05	4.90	5.15
7	3.60	4.25	4.50	4.50	4.00	4.30
10	1.00	2.70	2.95	2.75	0.85	2.05
12	2.25	3.30	3.55	3.15	1.45	2.75
17	1.75	2.95	2.25	3.15	1.85	2.15
Number of Analyses	23	23	23	23	23	23
Average	1.34	2.19	2.35	2.23	1.13	1.52

Aug.	29	5.25	6.25	5.90	5.35	4.15	5.15	0
	31	3.15	3.95	4.15	3.95	3.35	4.30	0
Sept.	1	3.20	4.40	4.10	3.30	2.50	2.50	0
	3	4.35	6.60	6.05	4.90	4.40	5.25	0
	4	5.40	7.15	6.55	6.00	6.30	6.70	0.60
	5	4.45	7.05	5.75	4.75	4.80	5.35	0
	6	4.55	6.70	5.75	4.75	4.00	4.65	0
	10	4.15	6.05	5.60	4.70	3.90	4.70	0
	11	3.75	6.30	0.90	3.85	3.05	3.75	0
	12	3.00	6.15	2.25	3.70	6.40	3.10	0
	14	1.95	4.55	2.50	1.30	1.90	2.20	0
	26	4.20	6.55	4.35				0
	27	5.70	7.25	6.50				0.35
	28	4.55	6.75	5.95				1.20
	29	3.75	5.45	4.50				0
Oct.	1	5.00	7.10	6.20				1.40
	3	3.70	6.10	5.15				0
	4	4.20	5.50	5.10				[illegible]
	8	1.70	4.05	3.90				0
	10	5.50	6.20	6.50				0
	17	2.50	4.55	3.10	2.10	2.10	[illegible]	0
	31	4.20	7.45	5.45	4.05	5.35	5.55	1.1
Nov.	1	7.75	8.0	8.10	5.75	6.40	7.20	3.95
	5	5.40	7.55	6.90	4.65	[illegible]	4.60	0.60
	7	5.35	5.50	6.05	5.90	4.65	4.65	3.45
	8	4.20	7.35	6.40	5.35	4.35	4.50	1.55
	9	6.55	[illegible]	7.65	6.70	6.25	6.30	2.35
	12	6.30	9.05	8.40	6.75	5.55	5.40	0.20
	14	6.75	10.65	8.80	6.35	7.05	5.55	4.45
	19	3.90	6.20	5.10	3.25	2.65	2.95	1.00
	25	4.10	5.45	4.60	3.60	4.75	4.50	1.95
	28	4.65	5.60	4.95	4.65	3.70	3.55	0.55
Dec.	5	2.70	5.30	4.35	2.20	1.35	2.35	0.55
	7	5.75	6.10	7.30	6.05	[illegible]	5.35	2.10
	10	6.95	7.20	[illegible]	6.40	[illegible]	4.65	[illegible]
Number of Analyses		35	35	35	26	26	26	26
Average		4.52	6.57	5.52	4.32	4.21	4.65	0.72

Second Operating Period - 4 M.G.A.D., 3 min. Cycle.

Dec.	12	5.55	5.35	4.90	3.70	3.05	1.50	0
	14	1.30	5.80	2.50	2.35	0.55	0.90	0
	17	2.45	4.40	3.40	3.05	1.35	2.40	0.85
	29	4.05	5.65	3.95	4.35	3.35	5.25	0
	31	1.25	2.65	1.90	2.00	0.75	1.65	0
Jan.	2	2.35	1.55	1.50	0.85	0.45	1.15	0
	4	5.20	5.30	4.60	3.65	2.15	4.10	0
Feb.	14	0	0.70	0.50	tr.		0.45	0
	15	1.20	2.55	1.45	0.60	0.25	0.40	2.0
	18	0	0.75	0.65	0	0	0	0
	20	6.40	3.70	2.10	1.10	0.55	0.80	0.95
	22	0	1.00	0.75	tr.	tr.	0.40	0
	23	0.90	7.20	3.95	1.35	1.20	2.70	tr.
	27	0.45	6.90	3.60	2.35	1.90	4.20	[illegible]
March	1	0	1.20	0.75	0	0	1.10	0
	4	0	3.00	2.90	2.30	0	0.25	0
	8	2.65	[illegible]	4.50	[illegible]	0.45	0.55	0
	11	0	4.00	3.35	[illegible]	[illegible]	[illegible]	[illegible]

Table No. 7 Dissolved Oxygen Content of Filter Effluents
During First Operating Period.
2 M.G.A.D., 6 min. cycle.

Date		Dissolved Oxygen - p.p.m.						
		Granite	Raschig Rings				Straight's	Corn
			$\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	Block	Cobs
Aug.	29	5.25	6.25	5.90	5.35	4.15	5.15	0
	31	3.15	5.95	4.15	3.95	3.35	4.30	0
Sept.	1	3.20	4.40	4.10	3.30	2.50	2.30	0
	3	4.35	6.60	6.05	4.90	4.40	5.25	0
	4	5.40	7.15	6.35	6.10	6.10	6.70	0.50
	5	4.45	7.05	5.75	4.75	4.80	5.35	0
	6	4.55	6.70	5.75	4.75	4.00	4.65	0
	10	4.15	6.05	5.60	4.70	3.90	4.70	0
	11	3.75	6.30	0.90	3.85	3.05	3.55	0
	12	3.00	6.15	2.25	3.70	3.40	3.50	0
	14	1.95	4.35	2.50	1.30	1.90	2.20	0
	26	4.20	6.55	4.35				0
	27	5.70	7.25	6.50				0.35
	28	4.55	6.75	5.95				1.20
	29	3.75	5.45	4.60				0
Oct.	1	5.05	7.10	6.25				1.40
	3	3.70	6.10	5.15				0
	4	4.20	5.70	5.10				0
	8	1.70	4.05	3.80				0
	10	5.00	6.90	6.50				0
	17	2.60	4.55	3.10	1.80	2.10	[illegible]	0
	31	4.20	7.45	6.45	4.05	5.85	6.65	1.1
Nov.	1	7.75	8.50	8.10	5.75	3.40	7.20	3.95
	5	5.40	7.55	6.90	4.65	4.45	4.60	0.60
	7	5.35	7.50	6.05	5.90	4.85	4.85	2.45
	8	4.20	7.35	6.40	5.35	4.35	4.50	1.65
	9	6.55	8.55	7.65	6.75	5.55	6.50	2.35
	12	6.30	9.05	8.40	6.75	5.55	6.40	0.80
	14	6.75	10.85	9.20	2.05	7.85	7.55	4.45
	19	3.90	6.20	5.10	5.25	2.05	2.95	1.00
	23	4.10	5.45	4.60	3.60	4.75	4.50	1.95
	28	4.65	5.60	4.95	4.65	3.70	3.35	0.55
Dec.	5	2.70	5.30	4.35	2.80	1.85	2.35	0.65
	7	5.75	6.10	7.50	6.05	5.15	5.95	2.10
	10	6.95	7.20	7.30	6.40	2.70	4.85	0
Number of Analyses		35	35	35	26	26	26	26
Average		4.52	6.57	5.52	4.22	4.21	4.85	0.72

Second Operating Period - 4 M.G.A.D., 3 min. Cycle.

Dec.	12	5.55	6.35	4.90	3.70	3.05	1.50	0
	14	1.30	3.80	2.50	2.55	0.55	0.90	0
	17	2.45	4.40	3.10	3.05	1.35	2.40	0.25
	20	4.05	5.65	5.95	4.35	3.35	5.25	0

	10							2
	11							2
	12							3
	14							-
	17							3
	20	96						3
	22	99*				95		3
	24	99*				87		2
	26	99*			96	94		2
	27	96			96	98	84	3
	28	99*			90	90	99*	4
	29	99*			98	87	99*	2
Oct.	1	99*			99	98	99	11
	3	99*			97	90	98	4
	4	97			96	84	98	1
	5	99*			99*	99*	99*	4
	8	90			96	80	99	2
	10	99*			98	97	99*	4
	12	99*			37	99*	99*	3
	15	99*	37		50	99	21	1
	17	99*	99*		99*	99*	99*	1
	18	99*			99*		80	1
	19						99*	2
	22							21
	24							
	25							
	26							
	30				96	94	80	
	31		92		98	80	98*	
Nov.	1	84	99*		90	99*		
	5	99*			94	92		
	7	99*			99*	99*		
	8							
	9							
	12							
	14							
	19							
	23							
	28							3
Dec.	5	80						3
	7	99*				84	94	3
	10	99*				99*	99*	5
Number of Analyses		52	52	52	52	52	52	51
Average		96.3	97.7	99*	95.5	94.6	96.3	9.6

(*) Sample was not decolorized at time indicated.

	24	20*				9		2 hr.
	26	20*			15	12		2 hr.
	27	15			15	18	8	3 hr.
	28	20*			10	10	20*	4 hr.
	29	20*			19	9	20*	2 hr.
Oct.	1	20*			20	18	20	12 hr.
	3	20*			16	7	19	4 hr.
	4	17			14	8	18	1 hr.
	5	20*			20*	20*	20*	4 hr.
	8	10			14	7	20	2 hr.
	10	20*			19	17	20*	4 hr.
	12				2	20*	20*	3 hr.
	15		2		3	20	1	1 hr.
	17		20*		20*	20*	20*	1 hr.
	18						7	1 hr.
	19						20*	2 hr.
	22						20*	1
	24						20*	1
	25						20*	1
	26					28	20*	1
	29				14	12	7	1
	31		11		10	7	20*	1
Nov.	1	8	20*		10	20*	25	1
	5	21			12	11	20*	1
	7	20*			20*	20*		1
	8				20*	20*		1
	9				20*	20*		1
	12				20*	20*		1
	14				28	34		1
	19				20*	20*		1
	23				20*	20*		1
	26				20*	20*		3 hr.
Dec.	5	7			24	20*	24	3 hr.
	7	22		22	22	8	12	3 hr.
	10	20*		20*	20*	20*	20*	5 hr.

Relative Stability - per cent.

Aug.	25	75	99*	99*	75	92	99*	50
	28	99*			99*	84		11
	29	99*				97		3
	31	99*				68		4
Sept.	1	99*				99*		2
	3	80						3
	4	75						11
	5	80				68		4
	6	99*				98		4
	7					99*		3
	10							2
	11							2
	12							3
	14							-
	17							3
	20	96						3
	22	99*				96		3
	24	99*				87		2
	26	99*			96	94		2
	27	96			96	98	84	3
	28	99*			90	90	99*	4
	29	99*			98	87	99*	2
Oct.	1	99*			99	98	99	11
	3	99*			97	80	98	4

Table No. 8 Relative Stability of Filter Effluents
During First Operating Period.
2 M.G.A.D., 6 min. cycle.

Date	Time Required for Decolorization at 20°C - Days						
Filter	Granite	Raschig Ring Filters				Straight's	Corn
		$\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	Block	Cobs
Aug. 25	6	20*	20*	6	11	20*	3
28	20*			20*	8		12 hr.
29	20*				16		3 hr.
31	20*				5		6 hr.
Sept. 1	20*				20*		2 hr.
3	7				20*		6 hr.
4	6				20*		6 hr.
5	7				5		4 hr.
6	20*				19		4 hr.
7					20*		3 hr.
10							2 hr.
11							2 hr.
12							3 hr.
14							-
17							3 hr.
20	15						3 hr.
22	20*				15		3 hr.
24	20*				9		2 hr.
26	20*			15	12		2 hr.
27	15			15	18	8	3 hr.
28	20*			10	10	20*	4 hr.
29	20*			19	9	20*	2 hr.
Oct. 1	20*			20	18	20	12 hr.
3	20*			16	7	19	4 hr.
4	17			14	8	18	1 hr.
5	20*			20*	20*	20*	4 hr.
8	10			14	7	20	2 hr.
10	20*			19	17	20*	4 hr.
12				2	20*	20*	3 hr.
15		2		3	20	1	1 hr.
17		20*		20*	20*	20*	1 hr.
18						7	1 hr.
19						20*	2 hr.
22						20*	1
24						20*	1
25						20*	1
26					28	20*	1
29				14	12	7	1
31		11		13	7	20*	1
Nov. 1	8	20*		10	20*	25	1
5	21			12	11	20*	1
7	20*			20*	20*		1
8				20*	20*		1
9				20*	20*		1
12				20*	20*		1
14				28	34		1
19				20*	20*		1
23				20*	20*		1
28				20*	20*		3 hr.

	29	2	20	16	7	2	6	2 hr.
	31	15	20*	20*	22	2	30	4 hr.
Jan.	2	3	20*	20	7	1	14	2 hr.
	4	5	18	14	5	1	5	1 hr.
Feb.	14	3 hr.	12 hr.	12 hr.	3 hr.	3 hr.	3 hr.	3 hr.
	15	2	1	1	4 hr.	4 hr.	4 hr.	2 hr.
	18	1	1	1	1	1	1	-
	20	-	-	4 hr.	2 hr.	2 hr.	2 hr.	2 hr.
	22	2 hr.	1	2 hr.	2 hr.	2 hr.	2 hr.	2 hr.
	25	4 hr.	18	1.5	1	1	1	1
	27	3 hr.	20*	1	1	3 hr.	1	3 hr.
March	1	2 hr.	3	1.5	1	1	1	2 hr.
	4	4 hr.	20*	18	20*	3 hr.	12 hr.	4 hr.
	8	3.5	77*	32	77*	13	1	-
	11	1	30	20	3	3 hr.	3	3 hr.
	13	6 hr.	54	72*	6 hr.	6 hr.	6 hr.	6 hr.
	15	3 hr.	59	33	6 hr.	3 hr.	3 hr.	2 hr.
	18	3 hr.	67*	67*	5	12 hr.	5	3 hr.
	25	33	60*	60	49	4	60*	6 hr.
	27	6 hr.	58*	58*	19	2	27	0
April	1	55*	55*	55*	55*	15	30	2 hr.

Relative Stability - per cent

Dec.	12	80	99*	99*	68	37	21	1
	14	99*	-	99*	99*	96	99*	3
	17	90	99*	99*	96	68	90	1
	21	90	[illegible]	99*	99*	68	99*	7
	29	37	99	97	80	37	75	2
	31	96	99*	99*	99*	37	99*	4
Jan.	2	56	99*	90	80	21	96	2
	4	68	98	96	63	21	62	1
Feb.	14	3	11	11	3	3	3	3
	15	37	21	21	4	4	4	2
	18	21	21	21	21	21	21	-
	20	-	-	4	2	2	2	2
	22	2	21	2	2	2	2	2
	25	4	96	30	21	21	21	21
	27	3	99*	[illegible]	21	3	21	[illegible]
March	1	2	30	30	21	21	21	2
	4	4	99*	98	99*	3	[illegible]	[illegible]
	8	5	99*	99*	99*	[illegible]	[illegible]	[illegible]
	11	21	[illegible]	99	60	3	56	3
	13	7	[illegible]	99*	7	5	7	7
	15	7	[illegible]	[illegible]	7	3	5	2
	18	3	[illegible]	[illegible]	68	11	68	5
	25	99*	[illegible]	[illegible]	99*	60	99*	7
	27	7	[illegible]	[illegible]	98	31	[illegible]	[illegible]
April	1	99*	[illegible]	[illegible]	99*	96	99*	2
Num[illegible]								
[illegible]		[illegible]	98	25	25	25	25	25
Average		42	93	72	56	31	48	4

(*) Sample was not deteriorated at time indicated.

Table No. 9 Relative Stability of Filter Effluents During Second Operating Period. 4 M.G.A.D., 3 min. Cycle.

Date		Time Required for Decolorization at 20°C. - Days						
Filter		Granite	Raschig Ring Filters				Straight's Block	Corn Cobs
			¾ in.	1 in.	1½ in.	2¼ in.		
Dec.	12	7	20*	20*	5	2	1	1 hr.
	14	20*	-	20*	20*	15	20*	3 hr.
	17	10	20*	20*	14	5	10	1 hr.
	21	10	20*	20*	20*	5	24	6 hr.
	29	2	20	16	7	2	6	2 hr.
	31	15	20*	20*	22	2	30	4 hr.
Jan.	2	3	20*	20	7	1	14	2 hr.
	4	5	18	14	5	1	5	1 hr.
Feb.	14	3 hr.	12 hr.	12 hr.	3 hr.	3 hr.	3 hr.	3 hr.
	15	2	1	1	4 hr.	4 hr.	4 hr.	2 hr.
	18	1	1	1	1	1	1	-
	20	-	-	4 hr.	2 hr.	2 hr.	2 hr.	2 hr.
	22	2 hr.	1	2 hr.	2 hr.	2 hr.	2 hr.	2 hr.
	25	4 hr.	18	1.5	1	1	1	1
	27	3 hr.	20*	1	1	3 hr.	1	3 hr.
March	1	2 hr.	3	1.5	1	1	1	2 hr.
	4	4 hr.	20*	18	20*	3 hr.	12 hr.	4 hr.
	8	3.5	77*	32	77*	13	1	-
	11	1	30	20	3	3 hr.	3	3 hr.
	13	6 hr.	54	72*	6 hr.	6 hr.	6 hr.	6 hr.
	15	3 hr.	59	33	6 hr.	3 hr.	3 hr.	2 hr.
	18	3 hr.	67*	67*	5	12 hr.	5	3 hr.
	25	33	60*	60	49	4	60*	6 hr.
	27	6 hr.	58*	58*	19	2	27	0
April	1	55*	55*	55*	55*	15	30	2 hr.

Relative Stability - per cent

Date		Granite	¾ in.	1 in.	1½ in.	2¼ in.	Straight's Block	Corn Cobs
Dec.	12	80	99*	99*	68	37	21	1
	14	99*	-	99*	99*	96	99*	3
	17	90	99*	99*	96	68	90	1
	21	90	99*	99*	99*	68	99*	7
	29	37	99	97	80	37	75	2
	31	96	99*	99*	99*	37	99*	4
Jan.	2	50	99*	99	80	21	96	2
	4	68	98	96	68	21	68	1
Feb.	14	3	11	11	3	3	3	3
	15	37	21	21	4	4	4	2
	18	21	21	21	21	21	21	-
	20	-	-	4	2	2	2	2
	22	2	21	2	2	2	2	2
	25	4	98	30	21	21	21	21
	27	3	99*	21	21	3	21	3
March	1	2	50	50	21	[illegible]	[illegible]	2
	4	4	99*	[illegible]	99*	3	[illegible]	4
	8	[illegible]	[illegible]	99*	99*	97	[illegible]	[illegible]
	11	21	[illegible]	99	[illegible]	3	[illegible]	3

Filter		Granite	Raschig Ring Filters $\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Straight's Block
April	3	2	52*	23	3	2	5
	8	4	47*	47*	11	2	1
	10	1	45*	45*	3	7	3
	12	6	70	84	17	1	6
	17	6 hr.	3	2	3 hr.	6 hr.	3
	19	3	22	8	3	4	7
	22	2	32	26	21	-	3
	24	1	17	47	7	2	10
	26	3 hr.	31	17	8	-	3 hr.
	29	6		51	28	7	26
May	1	3	28	26	5	3	3
	6	4	19	49	19	12	18
	8	3	20	39	17	3	15
	13	3	28	20	3	3	3
	17	10	43	48	40	6	19
	20	5	46*	46	25	9	17
	22	3	11	11	35	3	5
	29	4	37*	37*	37*	4	28
June	3	10	33*	33*	33*	3	12
	5	31*	31*	31*	31*	31*	31*
	7	29*	29*	29*	29*	17	29*
	10	18	26*	26*	26*	10	26*
	12	24*	24*	24*	24*	12	24*
	17	20*	20*	20*	20*	20*	20*

Relative Stability - per cent.

April	3	37	99*	99*	50	37	68
	8	60	99*		92	37	21
	10	21	99*		50	80	50
	12	75	99*		97	21	75
	17	11	50	37	99*	11	50
	19	50	99*	84	50	60	80
	22	37	99*	99*	99*	-	50
	24	21	97	99*	80	37	90
	26	3	99*	97	84	-	3
	29	75	99*	99*	99*	80	99*
May	1	50	99*		68	50	50
	6	60	98		98	94	98
	8	50	99	99	97	50	96
	13	50	99*	99*	50	50	50
	17	90	99*	99*	99*	75	98
	20	68	99*	92		87	97
	22	50	92	99*		50	68
	29	60	99*			60	99*
June	3	97	99*			50	94
	5	99*	99*			99*	99*
	7	99*	99*			97	99*
	10	98	99*			90	
	12	99*	99*			94	
	17	99*	99*			99*	
Number of Analyses		24	24	24	24	22	24
Average		61	97	95	84	64	76

Table No. 10 Relative Stability of Filter Effluents
During Third Operating Period.
8 M.G.A.D., 3 min. cycle.

Date		Time Required for Decolorization at 20°C. - Days					
Filter		Granite	Raschig Ring Filters				Straight's
			½ in.	1 in.	1½ in.	2¼ in.	Block
April	3	2	52*	23	3	2	5
	8	4	47*	47*	11	2	1
	10	1	45*	45*	3	7	3
	12	6	70	84	17	1	6
	17	6 hr.	3	2	3 hr.	6 hr.	3
	19	3	22	8	3	4	7
	22	2	32	26	21	-	3
	24	1	17	47	7	2	10
	26	3 hr.	31	17	8	-	3 hr.
	29	6		51	28	7	26
May	1	3	28	26	5	3	3
	6	4	19	49	19	12	18
	8	3	20	39	17	3	15
	13	3	28	20	5	3	3
	17	10	43	48	40	6	19
	20	5	46*	46	25	9	17
	22	3	11	11	35	3	5
	29	4	37*	37*	37*	4	28
June	3	16	33*	33*	33*	3	12
	5	31*	31*	31*	31*	31*	31*
	7	29*	29*	29*	29*	17	29*
	10	18	26*	26*	26*	10	26*
	12	24*	24*	24*	24*	12	24*
	17	20*	20*	20*	20*	20*	20*

Relative Stability - per cent.

April	3	37	99*	99*	50	37	68
	8	60	99*		92	37	21
	10	21	99*		50	80	50
	12	75	99*		97	21	75
	17	11	50	37	99*	11	50
	19	50	99*	84	50	60	80
	22	37	99*	99*	99*	-	50
	24	21	97	99*	80	37	90
	26	3	99*	97	84	-	3
	29	75	99*	99*	99*	80	99*
May	1	50	99*		68	50	50
	6	60	98		98	94	98
	8	50	99	99	97	50	96
	13	50	99*	99*	50	50	50
	17	90	99*	99*	99*	75	98
	20	68	99*	92		87	97
	22	50	92	99*		50	68
	29	60	99*			60	99*
June	3	97	99*			50	94

	31	1.9	0.8	2.5	1.7	2.1	4.7	[illegible]
Jan.	2	2.2	1.0	2.9	1.9	3.8	3.8	1.5
	4	5.3	3.3	4.1	3.9	6.5	5.2	1.6
Feb.	14	0.3	0.2	0.3	0.2	0.4	0.4	0.3
	15	0.1	0	0	0	[illegible]	0	[illegible]
	18	0.7	0	0.1	0.6	1.4	0.2	0.1
	20	0.2	0.5	0.6	3.0	2.6	2.8	0.1
	22	2.0	0.3	0.7	1.6	2.1	2.5	1.5
	25	1.0	0.6	[illegible]	1.8	0.9	0.9	0.7
	27	1.1	0.4	1.4	1.2	1.4	0.6	0.7
March	1	2.0	2.4	3.2	2.5	[illegible]	1.5	[illegible]
	4	2.0	2.6	4.1	1.6	1.4	1.4	0.8
	8	0.4	1.6	2.1	1.2	1.4	1.6	0.5
	11	3.8	2.7	4.2	3.0	5.7	[illegible]	1.2
	13	2.9	0.6	1.5	2.0	2.7	2.6	[illegible]
	15	[illegible]	1.1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	18	4.0	-	3.5	4.4	6.2	7.8	1.2
	25	46.1	10.4	[illegible]	[illegible]	[illegible]	10.0	[illegible]
	27	[illegible]	[illegible]	[illegible]	1.0	[illegible]	[illegible]	1.7
April	1	5.2	2.8	10.0	3.4			
	3	4.1	[illegible]	[illegible]	3.2			
Number of Analyses		25	24	25	25	[illegible]	[illegible]	[illegible]
Average		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Third Period of Operation - 8 M.G.A.D. - 6 min. cycle

April	8	4.1	[illegible]	[illegible]	3.0		
	10	5.4	[illegible]	4.8	[illegible]		
	15	6.1	4.4	[illegible]	[illegible]		
	17	4.2	3.2	2.9	2.6		
	19	2.3	0.6	0.8	2.3		
	22	2.6	[illegible]	[illegible]	2.5		
	24	2.2	[illegible]	3.7	[illegible]		
	26	2.2	[illegible]	[illegible]	[illegible]		
	29	[illegible]	[illegible]	[illegible]	1.4		
May	1	[illegible]	2.8	4.0	2.0		
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
	8	5.2	[illegible]	3.7	3.3		
	13	5.4	7.0	5.5	4.0	3.2	6.5
	17	[illegible]	[illegible]	3.3	4.2	9.2	[illegible]
	20	[illegible]	[illegible]	4.7	4.3	6.4	[illegible]
	22	6.1	5.1	[illegible]	5.0	8.6	[illegible]
	29	5.7	3.7	5.0	5.2	5.6	[illegible]
June	3	8.0	4.0	5.5	6.4	[illegible]	7.6
	5	6.0	2.2	3.0	3.9	5.1	[illegible]
	7	5.1	1.8	[illegible]	4.0	5.3	4.6
	10	[illegible]	4.0	5.1	7.3	9.2	[illegible]
	12	[illegible]	[illegible]	5.3	5.3	4.5	[illegible]
	17	7.2	4.0	5.0	6.4	7.1	6.4
Number of Analyses		23	23	23	23	11	11
Average		5.04	[illegible]	3.93	[illegible]	[illegible]	6.07
		(6.47)x	(4.25)x	(4.20)x	(3.10)x		

(x) Average of last eleven values. Comparable to values for 2½ inch ring and Straight's Block filter.

Table No. 11 Settlable Solids in Filter Effluents

Settlable solids - cc per L. in 1 hr.

Date		Granite	Raschig Rings $\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Straight's Block	Corn Cobs
First Period of Operation - 2 M.G.A.D. - 6 min. cycle								
Nov.	23	6.8	3.1	[illegible]	[illegible]	[illegible]	[illegible]	1.9
	28	6.7	5.[illegible]	7.4	[illegible]	[illegible]	[illegible]	[illegible]
Dec.	5	3.5	0.7	1.8	3.0	3.4	[illegible]	[illegible]
	7	3.9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	10	4.1	[illegible]	[illegible]	[illegible]	6.4	5.0	[illegible]
	12	3.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.4
Number of Analyses		6	6	6	[illegible]	6	6	[illegible]
Average		4.7	2.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Second Operating Period - 4 M.G.A.D. - 3 min. cycle								
Dec.	14	[illegible]	4.0	4.2	[illegible]	2.4	6.0	
	17	6.1	0.3	2.4	1.6	1.8	[illegible]	0.7
	21	5.2	1.1	3.1	1.8	[illegible]	[illegible]	1.5
	29	1.1	2.4	2.8	1.5	1.0	1.8	1.1
	31	1.9	0.6	[illegible]	1.7	[illegible]	4.8	[illegible]
Jan.	2	2.2	1.0	2.9	1.9	[illegible]	[illegible]	[illegible]
	4	5.3	[illegible]	[illegible]	[illegible]	6.5	5.2	1.6
Feb.	14	0.3	0.2	0.3	0.2	0.4	0.4	0.3
	15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	18	[illegible]	[illegible]	0.1	0.6	1.4	[illegible]	0.1
	20	0.2	[illegible]	[illegible]	[illegible]	2.6	[illegible]	0.1
	22	2.0	0.5	0.7	1.8	[illegible]	2.5	1.5
	25	1.0	0.6	[illegible]	1.2	0.9	0.9	0.7
	27	1.1	0.4	1.4	1.2	1.4	0.6	0.7
March	1	2.0	2.4	[illegible]	[illegible]	[illegible]	1.5	1.2
	4	2.0	2.6	4.1	1.6	1.4	1.4	0.8
	8	0.4	1.6	2.1	1.2	1.4	[illegible]	0.5
	11	[illegible]	2.7	4.2	3.0	[illegible]	[illegible]	[illegible]
"	13	2.9	0.6	1.5	[illegible]	[illegible]	2.6	[illegible]
	15	2.2	1.1	[illegible]	[illegible]	3.4	[illegible]	[illegible]
	18	4.0	-	3.5	[illegible]	[illegible]	7.9	[illegible]
	[illegible]	[illegible]	10.[illegible]	[illegible]	10.[illegible]	[illegible]	10.0	[illegible]
	[illegible]	[illegible]	[illegible]	10.[illegible]	10.[illegible]	[illegible]	[illegible]	[illegible]
April	1	[illegible]	[illegible]	12.[illegible]	3.4			
	3	4.1	4.7	4.2	3.[illegible]			
Number of Analyses		25	24	25	25	[illegible]	[illegible]	[illegible]
Average		4.4	2.2	3.2	2.9	[illegible]	[illegible]	[illegible]

Third Period of Operation - 6 M.G.A.D. - 3 min. cycle

[illegible]	[illegible]	84
24	6[illegible]	74
25	7[illegible]	84
26	70	82
27	70	93
28	70	88
29	68	79
30	67	62
31	6[illegible]	8[illegible]
Sept. 1	69	78
2	69	76
3	66	81
4	67	76
5	68	65
6	68	76
7	68	82
8	68	81
9	6[illegible]	86
10	68	73
11	68	88
12	68	85
13	68	74
14	68	61
15	67	61
16	67	74
17	67	7[illegible]
18	67	85
19	66	81
20	66	74
22	66	68
24	67	84
25	66	73
26	64	37
27	66	65

8	65	7[illegible]
9	66	80
10	6[illegible]	76
11	65	76
12	66	75
13	66	7[illegible]
15	66	71
17	-	61
18	66	57
19	66	55
20	66	76
21	65	74
23	65	63
24	66	6[illegible]
25	66	6[illegible]
26	6[illegible]	7[illegible]
27	65	55
28	64	58
29	64	37
30	66	62
31	65	54
Nov. 1	65	52
2	63	58
4	61	56
5	63	62
6	62	64
7	64	64
8	63	54
9	62	59
10	63	5[illegible]
11	61	46
12	58	49
13	62	59
14	62	52
15	62	5[illegible]
17	62	5[illegible]
19	62	59
20	61	61
22	60	75
23	60	[illegible]
25	61	75
26	60	76
27	61	63
28	61	77
29	61	72
30	59	69
Dec. 1	61	66
2	59	43
4	59	42
5	58	58
6	58	65
7	56	65
8	57	[illegible]
9	58	60
10		50
11	56	60
Number of Det'ns	102	101
Ave.	6[illegible].3	5[illegible].3

Table No. 2 Temperatures During First Operating Period.

Date		Temperature - Deg. F. Influent	Room	Date		Temperature - Deg. F. Influent	Room
Aug.	16	70		Sept.	28	66	65
	17	71			30	69	76
	18	71	65	Oct.	1	67	72
	19	71	77		2	67	[illegible]
	20	[illegible]	80		3	65	74
	21	71	[illegible]		4	66	70
	22	70	81		5	67	[illegible]
	23	70	84		[illegible]	65	[illegible]
	24	68	74		[illegible]	66	80
	25	[illegible]	[illegible]		10	[illegible]	78
	26	70	82		11	66	[illegible]
	27	70	95		12	69	78
	28	70	82		13	66	70
	29	68	79		15	66	[illegible]
	30	67	66		[illegible]	[illegible]	[illegible]
	31	67	82		17	66	[illegible]
Sept.	1	69	75		19	67	55
	2	69	76		20	66	[illegible]
	3	66	61		[illegible]	65	74
	4	67	76		23	66	[illegible]
	5	68	65		[illegible]	[illegible]	[illegible]
	6	68	76		25	68	[illegible]
	7	68	82		26	66	70
	8	67	81		27	65	55
	9	[illegible]	86		28	64	[illegible]
	10	68	73		29	64	57
	11	68	82		30	66	62
	12	68	85		31	66	64
	13	68	74	Nov.	1	63	52
	14	68	81		2	63	56
	15	67	61		4	61	56
	16	67	74		5	63	62
	17	67	72		6	62	64
	18	67	83		7	64	64
	19	68	81		8	63	54
	20	68	74		9	62	59
	22	66	68		10	63	59
	24	67	84		11	61	49
	25	68	73		12	63	[illegible]
	26	64	37		13	62	50
	27	66	65		14	62	52
					15	62	58
					17	62	56
					19	62	69
					20	61	61
					22	60	75
					23	60	[illegible]
					25	61	75
					[illegible]	[illegible]	[illegible]

Table No. 13 Temperatures During Second Operating Period.

Date	Temperature - Deg. F. Influent	Room	Date	Temperature - Deg. F. Influent	Room
Dec. 12	56	85	Feb. 23	51	89
13	58	105	24	51	90
14	57	74	25	49	60
15	57	92	26	50	40
16	57	94	27	49	90
17	57	103	28	50	90
18	59	80	March 1	51	84
19	57	58	2	50	70
20	56	80	3	50	78
21	57	90	4	48	94
22	56	72	5	43	80
24	55	37	6	48	85
26	57	59	7	50	70
27	54	80	8	50	65
28	57	82	9	50	80
29	53	80	11	50	100
30	54	80	12	50	110
31	55	88	13	50	86
Jan. 1	50	80	14	51	90
2	54	90	15	51	98
3	54	45	16	51	84
4		80	17	49	94
5	54	85	18	50	85
6	54	102	19	51	105
7	54	110	22	52	105
8	55	105	23	51	112
9	55	50	24	52	100
13	52	68	25	52	105
15		50	26	52	83
16	53	60	27	52	95
18	53	70	28	53	95
19	46	73	29	53	95
Feb. 13	53	80	30	52	105
14	50	80	31	52	115
15	46	86	April 1	51	100
16	49	88	2	52	70
17	48	74			
18	51	80	Number of		
19	51	70	Det'ns	77	78
20	50	66			
21	54	84	Aver.	52.2	83.2
22	52	80			

Table No. 14 Temperatures During Third Operating Period.

Date	Temperature - Deg. F. Influent	Room	Date	Temperature - Deg. F. Influent	Room
April 3	51	70	May 6	55	88
4	52	85	7	57	88
5	52	80	8	57	90
6	53	80	9	56	90
7	53	94	14	57	100
8	53	97	16	57	75
9	54	96	17	57	85
10	54	86	18	57	75
11	54	104	20	56	78
12	54	104	21	57	108
13	54	100	22	58	90
15	50	100	23	57	95
16		100	24	58	112
17	54	90	30	59	104
18	54	100	31	58	86
19	54	110	June 1	59	103
20	56	110	3	57	104
21	55	110	4	58	104
22	54	100	5	57	[illegible]
23	55	90	6	58	[illegible]
24	55	90	7	[illegible]	[illegible]
25	55	100	8	59	108
26	56	108	10	[illegible]	[illegible]
27	56	120	11	59	92
29	56	90	12	60	102
30	56	95	13	60	88
May 1	55	70	15	60	108
2	55	60	16	60	102
3	55	90	17	60	100
4	54	100	18	60	[illegible]
Number of Det'ns	60	61			
Aver.	56.03	95.1			

Table No. 15 Results Obtained During First Operating Period.
Dosage - 2 M.G.A.D., 6 Min. Cycle.

Comp. No.	FILTER EFFLUENTS							INFLUENT
	Granite	Raschig Rings				Straight's	Corn	Raw
		½ in.	1 in.	1½ in.	2½ in.	Block	Cobs	Sewage
NITRATES - p.p.m. as nitrogen								
I	4.8	7.2	14.3	2.9	0.4	0	0.3	0.5
II	8.4	22.9	11.7	6.3	7.4	9.4	0	0
III	1.7	8.6	15.7	9.0	1.0	3.6	tr.	tr.
IV	5.4	15.7	13.2	[illegible]	0	7.9	0.4	0.5
V	6.2	26.4	21.5	15.7	6.7	12.9	0.3	0.6
VI	10.7	30.8	25.1	14.1	5.2	11.0	1.0	0.8
Aver.	6.2	18.6	16.9	8.6	3.4	7.4	0.3	-
NITRITES - p.p.m. as nitrogen								
I	1.38	1.00	1.74	1.55	[illegible]	6.70	0	0
II	2.86	2.40	4.40	7.30	3.10	2.60	0	tr.
III	1.18	1.16	1.46	1.37	1.35	1.74	0.02	0
IV	1.22	1.33	1.32	1.31	3.10	3.93	0.33	0
V	0.83	0.57	0.68	0.70	0.85	1.01	1.40	0
VI	1.70	0.90	1.10	1.30	1.48	1.39	0.07	tr.
Aver.	1.53	1.23	1.68	2.28	2.21	2.89	0.30	tr.
FREE AMMONIA - p.p.m. as nitrogen								
I	27.0	12.4	14.0	22.2	19.1	15.4	8.4	22.5
II	10.5	1.5	5.3	8.0	17.6	5.1	23.1	31.8
III	16.5	3.3	9.4	15.3	22.0	11.4	32.0	34.6
IV	27.6	7.5	13.1	37.4	24.6	25.8	48.3	67.3
V	22.9	2.5	5.0	19.0	31.1	15.5	42.2	51.0
VI	20.7	[illegible]	12.8	14.2	24.3	21.2	52.0	56.0
Aver.	[illegible]	5.9	[illegible]	19.7	23.1	15.4	34.3	43.9
ORGANIC NITROGEN - p.p.m. as nitrogen								
I	8.5	2.8	6.2	8.8	18.5	10.0	11.0	19.6
II	4.9	3.2	2.4	2.7	10.4	6.5	18.2	20.2
III	5.5	4.2	5.9	5.9	7.5	6.6	8.4	9.2
IV	18.7	11.2	10.6	15.8	4.7	4.0	6.6	8.2
V	9.2	5.4	5.7	7.9	10.3	7.5	8.9	9.8
VI	11.7	5.6	8.3	7.4	8.7	16.0	11.1	9.3
Aver.	9.7	5.4	6.5	8.1	10.1	8.4	10.7	12.4

Table No. 15 Continued

Comp. No.	FILTER EFFLUENTS							INFLUENT
	Granite	Raschig Rings				Straight's	Corn	Raw
		$\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Block	Cobs	Sewage
OXYGEN CONSUMED - p.p.m. as oxygen								
I	66	65	49	63	71	59	137	139
II	65	62	64	64	70	71	86	118
III	69	65	69	68	66	62	81	83
IV	73	81	70	73	65	68	89	81
V	66	64	63	69	62	65	76	76
VI	72	60	65	70	69	73	77	70
Aver.	68	66	63	68	67	66	91	94
pH								
III	-	6.4	6.7	7.1	7.2	7.0	7.5	7.3
IV	6.88	7.14	7.08	7.42	7.34	7.34	7.28	7.26
V	7.19	6.89	6.90	7.20	7.36	7.14	7.56	7.62
VI	7.42	7.28	7.02	7.07	7.30	7.29	7.42	7.52
Aver.	7.16	6.93	6.92	7.15	7.30	7.19	7.44	7.42
TOTAL SOLIDS - dry, p.p.m.								
I	624	676	546	498	501	497	551	484
II	544	562	618	568	623	562	494	631
III	599	633	653	605	622	663	629	817
IV	666	770	657	654	559	624	611	720
V	628	658	647	637	572	583	565	659
VI	699	676	677	675	665	684	639	681
Aver.	627	646	633	606	590	602	581	665
TOTAL SOLIDS - volatile, p.p.m.								
I	262	202	135	141	58	167	143	124
II	181	127	231	139	162	191	237	264
III	194	267	175	216	212	262	230	296
IV	239	343	260	242	206	237	248	328
V	231	250	246	263	199	196	213	250
VI	270	235	247	267	350	308	328	286
Aver.	229	237	216	211	194	225	216	258

Table No. 15 Continued

Comp. No.	FILTER EFFLUENTS							INFLUENT
	Granite		Raschig Rings			Straight's	Corn	Raw
	$\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.		Block	Cobs	Sewage
DISSOLVED SOLIDS - dry, p.p.m.								
I	-	-	-	-	515	481	520	491
II	507	550	571	654	563	500	597	531
III	561	604	583	579	604	602	602	685
IV	590	617	563	573	553	575	550	632
V	582	597	546	572	545	521	534	550
VI	697	615	609	606	589	582	600	654
Aver.	587	596	574	597	561	542	580	590
DISSOLVED SOLIDS - volatile, p.p.m.								
I	-	-	-	-	55	83	125	121
II	119	141	142	134	155	197	212	192
III	177	216	178	174	189	207	232	298
IV	215	197	178	205	181	167	204	262
V	202	248	176	218	171	169	183	179
VI	184	160	190	209	330	221	216	254
Aver.	179	192	173	188	180	172	195	218

Composite Sample I, Aug. 16 to 31: Plant being adjusted; irregular operation at times.

Composite Sample II, Sept. 1 to 20: Plant operation normal. Some irregularity occurred in sampling.

Composite Sample III, Sept. 21 to Oct. 10: Plant operation normal. Mechanical difficulties in sampling.

Composite Sample IV, Oct. 11 to 29: Irregular operation during early part of period. Twelve consecutive days of normal operation.

Composite Sample V, Oct. 30 to Nov. 17: Plant operation normal. Air and sewage temperatures rather low.

Composite Sample VI, Nov. 18 to Dec. 9: Plant heated artificially. Very irregular operation due to causes.

Table No.16Results Obtained During Second Operating Period.
Dosage - 4 M.G.A.D., 3 min. Cycle.

Comp. No.	FILTER EFFLUENTS Granite	Raschig Rings $\frac{3}{4}$ in.	Raschig Rings 1 in.	Raschig Rings $1\frac{1}{2}$ in.	Raschig Rings $2\frac{1}{4}$ in.	Straight's Block	Corn Cobs	INFLUENT Raw Sewage
NITRATES - p.p.m. as nitrogen								
VII	7.6	21.1	15.9	10.9	6.2	11.8	tr.	tr.
VIII	7.3	17.6	10.4	11.4	6.4	8.9	tr.	tr.
IX*	1.7	2.7	2.4	1.8	1.4	1.3	tr.	tr.
X	2.2	8.8	5.2	2.5	1.1	.8	-	-
XI	1.7	20.5	20.5	8.1	3.7	3.8	-	-
Aver.	4.7	17.0	13.0	8.2	4.1	6.3	tr.	tr.
NITRITES - p.p.m. as nitrogen								
VII	1.33	1.70	1.59	1.55	1.18	1.59	0.49	tr.
VIII	1.36	1.83	1.48	1.88	1.35	1.66	tr.	tr.
IX*	tr.	.34	.36	.18	tr.	tr.	tr.	ft. tr.
X	.15	1.23	.68	.40	tr.	.17	ft. tr.	ft. tr.
XI	.99	2.18	1.95	1.80	1.26	1.77	.07	.02
Aver.	.86	1.73	1.42	1.33	.95	1.27	0.15	tr.
FREE AMMONIA - p.p.m. as nitrogen								
VII	59.4	26.0	29.1	40.9	39.2	29.2	58.0	63.2
VIII	42.4	23.2	29.0	39.2	40.0	33.2	43.6	51.0
IX*	51.3	51.3	45.4	50.7	52.7	50.7	49.4	58.0
X	43.0	37.2	44.8	48.0	42.2	43.2	57.1	51.8
XI	44.0	17.0	23.6	34.0	44.8	32.8	47.2	46.0
Aver.	47.2	25.9	31.6	40.5	41.5	34.6	51.5	53.0
ORGANIC NITROGEN - p.p.m. as nitrogen								
VII	9.4	7.2	7.0	7.2	12.7	14.0	12.7	15.6
VIII	28.8	22.4	25.2	25.8	31.0	21.0	23.8	13.8
IX*	12.4	11.2	9.6	13.8	13.0	11.2	13.0	20.5
X	15.0	13.2	14.5	14.4	13.8	16.4	16.8	17.7
XI	28.8	15.5	17.7	22.3	20.4	29.7	17.3	17.0
Aver.	20.5	14.6	16.1	17.4	19.6	20.3	17.4	16.0

Table No. 16 Continued

Comp. No.	FILTER EFFLUENTS Granite	Raschig Rings ¾ in.	1 in.	1½ in.	2¼ in.	Straight's Block	Corn Cobs	INFLUENT Raw Sewage
OXYGEN CONSUMED - p.p.m. as oxygen								
VII	72	67	65	60	64	66	76	76
VIII	80	79	89	87	83	82	85	91
IX	63	57	61	68	67	71	64	79
X	60	55	58	57	64	60	66	68
XI	84	60	63	73	70	78	69	70
Aver.	72	64	67	69	70	71	72	77
pH								
VII	7.32	7.24	7.16	7.24	7.48	7.42	7.54	7.52
VIII	7.24	7.24	7.24	7.28	7.18	7.28	7.41	7.70
IX	7.48	7.46	7.40	7.28	7.30	7.34	7.32	7.36
X	6.90	7.07	7.20	7.35	7.35	7.46	7.40	7.40
XI	7.50	7.42	7.20	7.31	7.42	7.45	7.30	7.30
Aver.	7.29	7.31	7.24	7.27	7.34	7.39	7.39	7.46
TOTAL SOLIDS - dry, p.p.m.								
VII	605	702	699	665	701	714	802	708
VIII	607	832	722	805	772	766	548	796
IX	601	659	525	642	658	681	537	735
X	674	661	632	606	622	728	691	742
XI	986	840	877	832	919	1006	808	885
Aver.	695	739	691	710	734	779	677	773
TOTAL SOLIDS - volatile, p.p.m.								
VII	264	239	269	229	264	291	334	280
VIII	217	453	291	291	357	300	233	313
IX	217	238	186	258	308	375	225	370
X	250	226	178	197	214	274	284	328
XI	440	339	343	328	407	445	378	384
Aver.	278	299	253	261	309	337	290	335

Table No. 16 Continued

Comp. No.	FILTER EFFLUENTS Granite $\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Straight's Block	Corn Cobs	INFLUENT Raw Sewage
DISSOLVED SOLIDS - dry, p.p.m.							
VII	604	619	610	651	601	629	712	679
VIII	608	547	565	643	602	607	441	715
IX	628	597	587	716	684	549	616	614
X	636	557	606	632	617	641	683	736
XI	551	614	544	630	570	668	618	628
Aver.	605	587	582	654	615	619	614	674
DISSOLVED SOLIDS - volatile, p.p.m.							
VII	185	204	178	281	212	208	271	243
VIII	243	178	226	277	184	160	162	255
IX	210	189	204	372	288	229	256	249
X	197	137	144	232	198	226	235	320
XI	200	178	254	219	194	233	203	197
Aver.	207	177	201	272	215	211	225	252

Composite Sample VII, Dec. 10 to Jan. 4: Plant operation nearly normal. Some irregularity due to severe cold weather.

Composite Sample VIII, Jan. 5 to 20: Irregular operation due to severe cold weather. Plant froze at end of period.

Composite IX, Feb. 14 to 21: Plant thawed out and put into operation. This period is short. The sample is not a normal one, since it is taken after freezing the filters.

Composite X, Feb. 22 to March 11: Some irregular operation early in period due to severe cold weather. Sewage diluted with storm water during latter part of period.

Composite XI, March 12 to April 1: Normal plant operation. The spring sloughing occurred during this period.

Table No. 17 Results Obtained During Third Operating Period. Dosage 8 M.G.A.D., 3 min. cycle.

Comp. No.	FILTER EFFLUENTS Granite $\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{2}$ in.	Straight's Block		INFLUENT Raw Sewage
NITRATES - p.p.m. as Nitrogen							
XII	2.0	16.5	12.2	11.7	0.3	2.2	tr.
XIII	1.5	6.5	8.8	4.5	1.3	3.9	tr.
XIV	3.1	11.9	9.0	5.2	2.1	1.8	-
XV	6.8	17.0	13.5	8.2	4.0	8.5	-
Aver.	3.3	14.0	10.8	7.4	1.9	4.1	-
NITRITES - p.p.m. as Nitrogen							
XII	.08	3.20	1.02	1.04	0.11	2.12	0.14
XIII	.38	1.30	1.34	.99	1.30	1.02	tr.
XIV	1.66	3.48	2.34	1.44	1.44	1.35	.15
XV	2.03	2.60	2.13	2.13	1.53	2.45	.29
Aver.	1.04	2.64	1.71	1.40	1.09	1.73	0.15
FREE AMMONIA - p.p.m. as Nitrogen							
XII	52.0	33.0	40.4	49.0	64.0	38.0	54
XIII	32.6	38.5	39.0	27.8	25.0	33.0	33.2
XIV	28.7	14.9	18.0	20.0	21.3	20.7	21.4
XV	22.2	8.3	11.6	17.6	19.4	15.8	21.6
Aver.	33.9	23.7	27.2	28.6	32.4	26.9	32.6
ORGANIC NITROGEN - p.p.m. as Nitrogen							
XII	17.0	12.0	16.6	13.5	14.0	15.9	16.5
XIII	13.3	21.4	14.6	18.2	14.1	13.6	19.6
XIV	17.0	8.8	12.0	8.8	10.7	11.6	8.0
XV	19.8	9.5	11.7	14.7	12.0	18.0	10.4
Aver.	16.8	12.9	15.7	13.8	12.7	14.8	13.6

Table No. 17 Continued.

Comp. No.	FILTER EFFLUENTS Granite	Raschig Rings $\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Straight's Block	INFLUENT Raw Sewage
OXYGEN CONSUMED - p.p.m. as Oxygen							
XII	67	59	67	61	65	63	67
XIII	71	68	66	64	71	68	73
XIV	75	67	68	66	68	72	65
XV	70	64	70	63	67	68	73
Aver.	71	64	68	63	68	68	70
p^H							
XII	7.42	7.44	7.42	7.48	7.46	7.40	7.52
XIII	7.15	7.00	7.05	7.23	7.48	7.40	7.30
XIV	7.08	7.10	7.30	7.30	7.15	7.28	7.42
XV	7.40	7.40	7.28	7.28	7.32	7.3	7.36
Aver.	7.26	7.23	7.28	7.32	7.36	7.34	7.40
TOTAL SOLIDS - dry, p.p.m.							
XII	756	660	636	682	682	661	755
XIII	675	580	627	711	706	635	534
XIV	816	746	729	708	849	721	746
XV	704	707	772	731	743	725	753
Aver.	738	674	691	708	745	685	755
TOTAL SOLIDS - volatile, p.p.m.							
XII	292	206	183	224	240	237	247
XIII	364	359	283	406	361	341	494
XIV	377	371	261	228	349	243	327
XV	369	350	298	291	280	263	342
Aver.	350	321	256	287	307	271	352

Table No. 17 Continued.

Comp. No.	FILTER EFFLUENTS Granite	Raschig Rings ¾ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Straight's Block	INFLUENT Raw Sewage
DISSOLVED SOLIDS - dry, p.p.m.							
XII	640	564	604	627	638	604	699
XIII	524	556	513	546	586	590	414
XIV	602	561	578	587	554	578	616
XV	575	594	614	585	558	604	554
Aver.	585	568	577	586	584	594	571
DISSOLVED SOLIDS - volatile, p.p.m.							
XII	330	115	182	245	248	238	308
XIII	153	144	129	161	173	175	230
XIV	239	157	176	179	155	174	232
XV	137	164	172	150	138	167	153
Aver.	215	145	165	184	178	188	231

Composite Sample XII, April 2 to 23: Plant operation normal except for one day. Appearance of sewage changed. Previously the slime in the sewage was gray, black and amorphous. During this period it became gray and seemingly animated, fillimentous.

Composite Sample XIII, April 24 to May 16: Plant operation normal. Sewage temperature rising.

Composite Sample XIV, May 17 to June 16: Plant operation normal.

Composite Sample XV, June 7 to 18: Plant operation normal. Sewage was somewhat dilute at the end of composite period due to heavy rains.

3	71	64	68	63	68	68	75	70

pH

1	7.16	6.93	6.92	7.15	7.30	7.19	7.44	7.42
2	7.29	7.31	7.24	7.27	7.34	7.39	7.39	7.46
3	7.26	7.23	7.26	7.32	7.36	7.34	7.42	7.40

Total Solids - dry - p.p.m.

1	627	646	633	606	590	602	581	665
2	695	739	691	710	734	779	677	773
3	738	674	691	708	745	685		755

Total Solids - volatile - p.p.m.

1	229	237	216	211	194	225	216	258
2	278	299	253	261	309	337	290	335
3	350	321	256	287	307	271		352

Dissolved Solids - dry - p.p.m.

1	587	596	574	597	561	542	580	590
2	605	587	582	654	615	619	614	674
3	585	568	577	586	584	594		571

Dissolved Solids - volatile - p.p.m.

1	179	192	173	188	180	172	195	218
2	207	177	201	272	215	211	225	252
3	215	145	165	184	178	188		231

Settable Solids - c.c. per L. after 1 hour settling

1	4.7	2.4	3.8	4.1	4.8	4.5	2.7
2	4.4	2.2	3.2	2.9	2.6	3.1	0.8
3	5.04	3.51	3.93	3.80	6.71	6.07	

Notes

	Average Temperatures deg. F.		Dosage	
	Influent	Room	Rate	Cycle
1	65.0	69.3	2 M.G.A.D.	6 min.
2	52.2	83.2	4 M.G.A.D.	5 min.
3	56.0	95.1	8 M.G.A.D.	3 min.

1	31.5	23.4	28.8	34.8	37.9	37.4	32.4	
2	76.7	32.0	41.7	59.2	68.8	65.4	49.7	
3	59.2	61.1	67.7	52.7	69.1	73.5	45.0	

Relative Stability - per cent.

1	96	98	99*	95	95	96	10	
2	40	85	72	56	31	48	4	
3	61	97	95	84	64	76		

Dissolved Oxygen - p.p.m.

1	4.52	6.57	5.52	4.82	4.21	4.65	0.72	
2	1.42	3.47	2.76	1.94	0.86	1.68	0.27	
3	1.34	2.19	2.35	2.23	1.13	1.52		

Nitrates - p.p.m. as nitrogen

1	6.2	18.6	16.9	8.6	3.4	7.4	0.3	-
2	4.7	17.0	16.0	8.2	4.1	6.3	tr.	tr.
3	3.3	14.0	10.8	[illegible]	1.9	4.1	-	-

Nitrites - p.p.m. as nitrogen

1	1.55	1.25	1.68	2.26	2.21	2.69	0.30	tr.
2	0.96	1.73	1.42	1.35	0.95	1.27	0.15	tr.
3	1.04	2.64	1.71	1.40	1.09	1.73	tr.	0.15

Free Ammonia - p.p.m. as nitrogen

1	20.8	5.9	9.6	19.7	25.1	15.4	54.3	45.9
2	47.2	25.9	31.6	40.5	41.5	34.6	51.5	53.0
3	33.9	23.7	27.2	28.6	32.4	26.9	43.0	32.6

Organic Nitrogen - p.p.m.

1	9.7	5.4	6.5	8.1	10.1	8.4	10.7	12.4
2	20.5	14.6	16.1	17.4	19.5	20.3	17.4	16.0
3	16.8	12.9	13.7	13.8	12.7	14.8	14.6	13.6

Oxygen Consumed - p.p.m.

1	68	66	63	68	67	66	91	94
2	72	64	67	69	70	71	72	77
3	71	64	68	63	68	68	75	70

pH

1	7.16	6.93	6.92	7.15	7.30	7.19	7.44	7.42
2	7.29	7.31	7.24	7.27	7.34	7.39	7.39	7.46
3	7.26	7.23	7.26	7.32	7.36	7.34	7.42	7.40

Total Solids - dry - p.p.m.

Table No. 18 Summary of Operating Data.

Operating Period	Granite	Raschig Rings ¾ in.	1 in.	1½ in.	2¼ in.	Straight's Block	Corn Cobs	INFLUENT
B.O.D. Settled Sample - p.p.m.								
1	24	12	16.8	24.9	22.8	21.2	53.8	184
2	53.2	34.3	41.8	47.9	56.4	51.2	92.2	184
3	46.8	38.9	38.3	41.0	30.7	32.5	124	189
B.O.D. Shaken Sample - p.p.m.								
1	55.5	35.4	45.6	59.7	60.7	58.6	86.2	186
2	129.9	66.3	83.5	107.1	125.2	114.6	141.9	184.4
3	106	100	106	93.7	99.8	106	169	189
B.O.D. Reduction Due to Settling - p.p.m.								
1	31.5	23.4	28.8	34.8	37.9	37.4	32.4	
2	76.7	32.0	41.7	59.2	68.8	63.4	49.7	
3	59.2	61.1	67.7	52.7	69.1	73.5	45.0	
Relative Stability - per cent.								
1	96	98	99+	95	95	96	10	
2	42	83	72	56	31	48	4	
3	61	97	95	84	64	76		
Dissolved Oxygen - p.p.m.								
1	4.52	6.57	5.52	4.82	4.21	4.65	0.72	
2	1.42	3.47	2.76	1.94	0.86	1.68	0.27	
3	1.34	2.19	2.35	2.23	1.13	1.52		
Nitrates - p.p.m. as nitrogen								
1	6.2	18.6	16.9	8.6	3.4	7.4	0.6	-
2	4.7	17.0	13.0	8.2	4.1	6.3	tr.	tr.
3	3.3	14.0	10.8	7.4	1.8	4.1	-	-
Nitrites - p.p.m. as nitrogen								
1	1.53	1.23	1.68	2.28	2.21	2.89	0.30	tr.
2	0.96	1.73	1.42	1.33	0.95	1.27	0.15	tr.
3	1.04	2.64	1.71	1.40	1.09	1.73	tr.	0.15

Free Ammonia - p.p.m. as nitrogen

C. Hydraulics of Trickling Filters.

1. Runoff Rate Studies.

Trickling filters are cutomarily dosed intermittently. Even when the so-called continuous dosing devices are used the rate of application does not remain constant at any given point on the surface of the filter. In the revolving arm type of continuous dosing devices, for example, the dose is intermittent with a dosing cycle equal to the time of one revolution of the dosing device. In most filters, however, the dosing cycle is anywhere from about 5 up to 30 or more minutes. It has been generally accepted in the past that this intermittent dosing of the filters was desirable in that it allowed a rest period during which time the oxygen of the air might reach all of the surface of the microbial film, to bring about the biological oxidation. More recently this idea has been challenged, and the tendency has been to reduce the time of the dosing cycle. The question has been raised as to whether a truly continuous application of waste is desirable or economically profitable, or whether there is a certain dosing time below which no advantage is gained.

When waste is intermittently applied to a filter the rate of application at a given point on the surface of the filter is very great at the instant of application, but becomes zero immediately afterwards. As the sewage flows into the filter bed this variation in rate of flow is reduced, and the rate of flow smoothed out. If the bed has sufficient depth the rate of runoff from the bottom of the filter is uniform. The amount of "smoothing out" action that may occur in a filter depends upon such things as the nature of the filter medium, the roughness of the surface, the interstice size, the nature and thickness of the film, etc. In most filters there is a surge in the runoff rate a few minutes after the application of the waste; that is, the runoff rate at the bottom of the filter is cyclic much as is the application rate, but lagging a few minutes. Levine (24) and others have shown that the purification obtained in the waste which flows out during this surge is much less than that obtained at the lower runoff rates. Furthermore it has been shown that the purification obtained at the time of maximum runoff rate is somewhat dependent upon the difference between maximum and minimum runoff rates. That is; it appears that the maximum purification is obtained when the runoff rate is more nearly uniform.

If the rate of application of a waste to the surface of the bed is great enough, the interstice space in the filter medium may be completely filled. Under this condition, the flow through the bed is defined as being flow in a closed channel. If the interstices are large, the flow is apt to be turbulent flow. If, however, the interstice space is limited or the microbial film is unusually heavy, the flow will be so restricted as to produce streamline flow. Flow through a slow sand filter in water purification practice illustrates this later condition. In most cases, however, the rate of application at the upper surface of the filter is not great enough to completely fill the interstices of the filter medium at any time. In this case the flow is defined as either turbulent or streamline motion in an open channel. The same limiting conditions obtain here as in other hydraulic calculations. As the film flowing over the filter medium becomes thin still another condition of flow sometimes spoken of as "capillary" flow obtains. This type of flow is peculiar to a trickling filter. The waste rather than flowing in thin films, flows through the microbial film, perhaps displacing the liquid constituent of the film, not unlike the flow through a lamp wick or through soil. This type of flow continues for some hours after the application to the top of a filter has ceased.

A study was made of the runoff characteristics of the various filter media operating under various conditions. The following procedure was used for determining the runoff rate. A container suspended on a spring balance was placed beneath the drain of the given filter so as to collect the total runoff from the filter. The spring balance used for this work was calibrated in tenths of a pound up to sixty pounds. An electric vibrator was attached to the spring balance in order to prevent sticking of the indicator. With the plant in operation for a considerable time to insure equilibrium conditions being reached, readings of the spring balance were made every ten seconds. The readings were estimated to one-hundredths of a pound. An electric clock, with a second hand, timed the experiment. A typical set of data obtained in this manner is shown on Table No. 19. No attempt was made to synchronize the start of the test with the dosing cycle. The time at which application of the dose occurred is shown, in parenthesis, in seconds. The readings taken on the minute are underlined. In general the experiment was continued until the container became filled. The readings obtained while operating at any one set of conditions covered at least three full cycles, and in many cases six or more. The data obtained in this fashion may be designated as cumulative runoff data. Typical data obtained in this fashion are plotted on Fig. (24), (25), and (26). In these figures one inch vertical distance represents one pound, while one inch horizontal distance represents 50 seconds. Since the absolute quantity under the curve is of no interest no attempt was made to plot these curves on the same base line. The point of application of the dose is indicated by means of an arrow.

The principal point of interest in these curves is the slope of the curves at any given point. That is, if the runoff rate becomes zero the runoff curve becomes horizontal and the slope zero. If the runoff rate increases to a large value the slope of the curve becomes large. Furthermore, if the runoff rate remains constant, the runoff curve becomes a straight line.

In Fig. (24) and (25) the runoff curve for the corncob filter is nearly a straight line indicating a constant runoff rate.

Runoff rate data were obtained from the runoff curves by a graphical integrating device which translated the slope of the line directly into runoff rate in pounds per minute. This graphical device, not unlike a protractor, was placed with one axis parallel with the axis of the graph paper and the other tangent to the curve at the point being studied, and the value of the runoff rate read off directly. The runoff rate data for three or more cycles were averaged to give an average runoff rate in pounds per minute. For the purpose of this investigation, the runoff rate, in pounds per minute, was converted to runoff rate in terms of per cent of average flow by dividing the first value by the average flow as determined by the slope of a straight line drawn between points of application on the runoff curves.

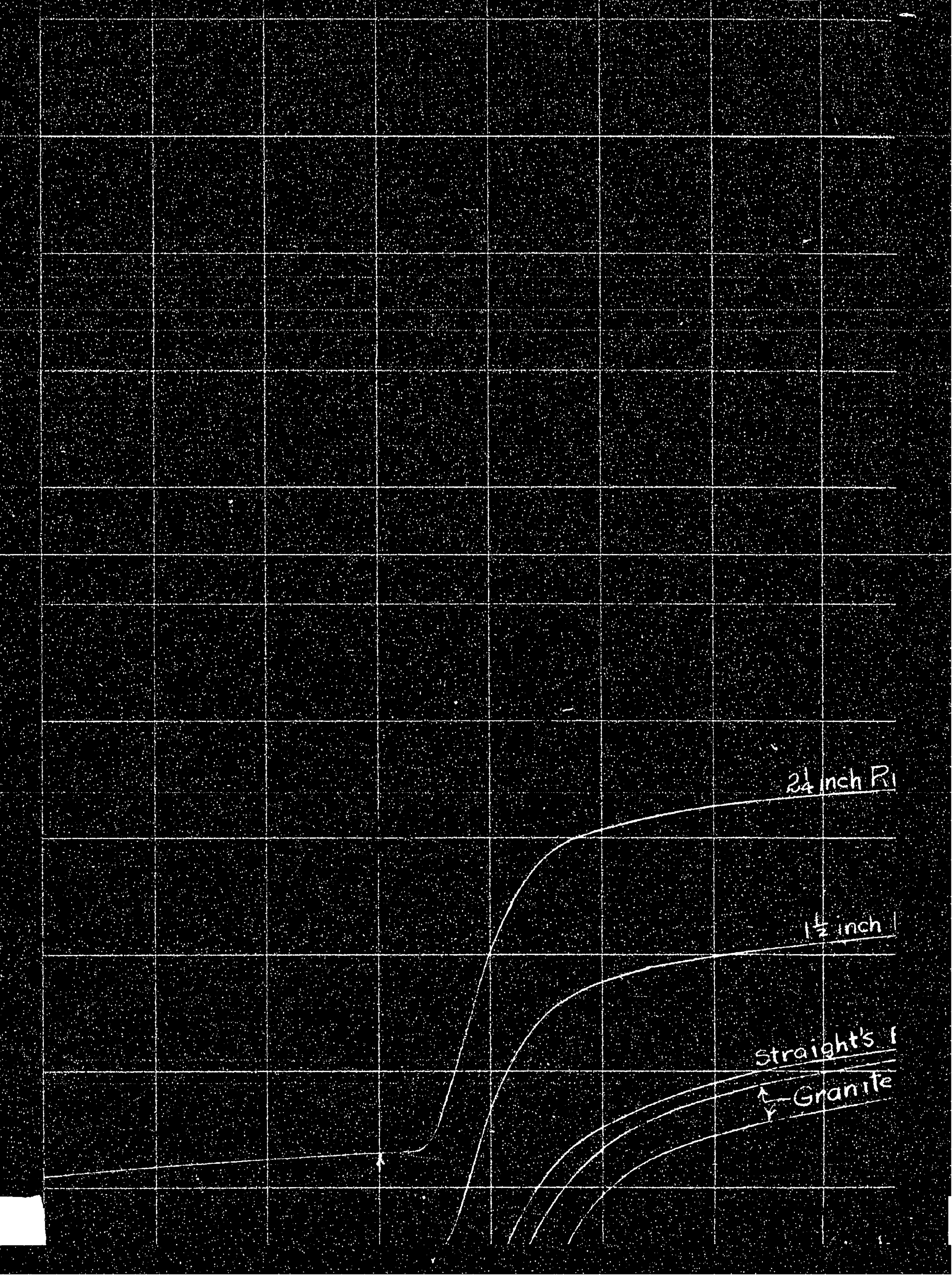
The runoff rate data in terms of per cent of average flow are given in Tables No. 20, 21, and 22, for each of the seven filters dosed at the rate of 2 M.G.A.D. and with a six minute cycle. The data in Table No. 20 were obtained when dosing the filters with water before a microbial film had developed. Table No. 21 gives similar data obtained when dosing the filters with sewage, but before the microbial film had developed. Table No. 22 gives similar data obtained when dosing the filters with sewage, with the microbial film developed. The runoff rate data

Table No. 19 Typical Runoff Data

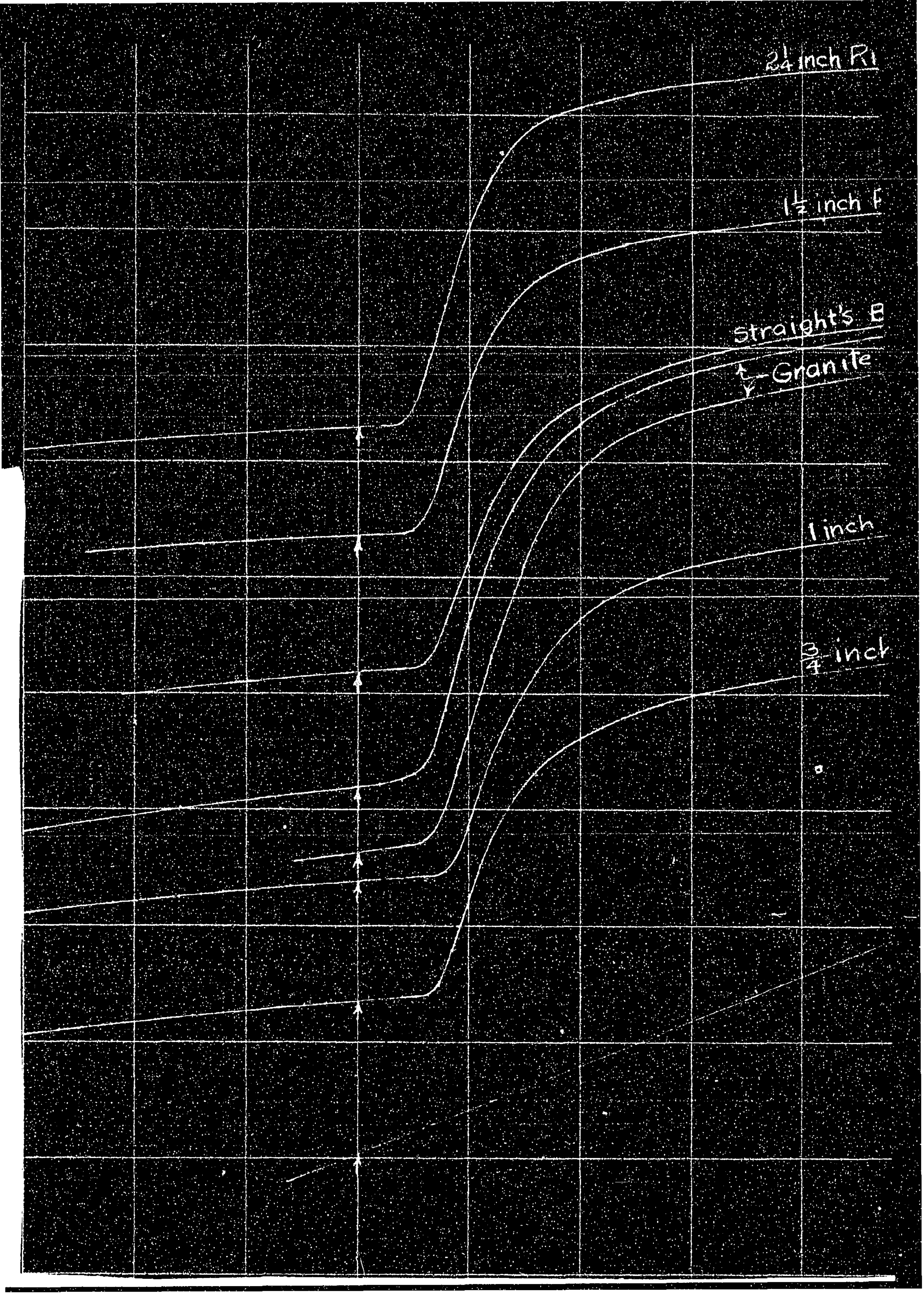
Conditions: Granite filter
2 M.G.[illegible]D., [illegible]
3 min. cycle
[illegible]
July [illegible], 19[illegible]

188	[illegible]	900	178	728
204	[illegible]	[illegible]	84	36
16	[illegible]	1014	90	44
24	718	92	96	53
36	40	1160	202	61
[illegible]	58	1210	08	69
56	70	50	14	76
[illegible]	86	75	18	82
72	98	1300	22	90
80	810	24	24	[illegible]
[illegible]	22	[illegible]	30	[illegible]
94	30	55	(48) 34	10
300	40	72	40	13
08	48	82	46	20
14	58	92	54	24
18	64	1406	60	30
[illegible]	72	14	350	[illegible]
30	76	24	428	(58) 40
[illegible]	86	[illegible]	84	41
40	92	[illegible]	532	52
[illegible]	98	45	74	54
52	903		600	83
(12) 58	08		26	96
67	12		40	974
68	18		58	1050
74	22		72	
[illegible]	28		84	
[illegible]	36		98	
524	(44) 40		706	
30	44		16	
532	50		28	

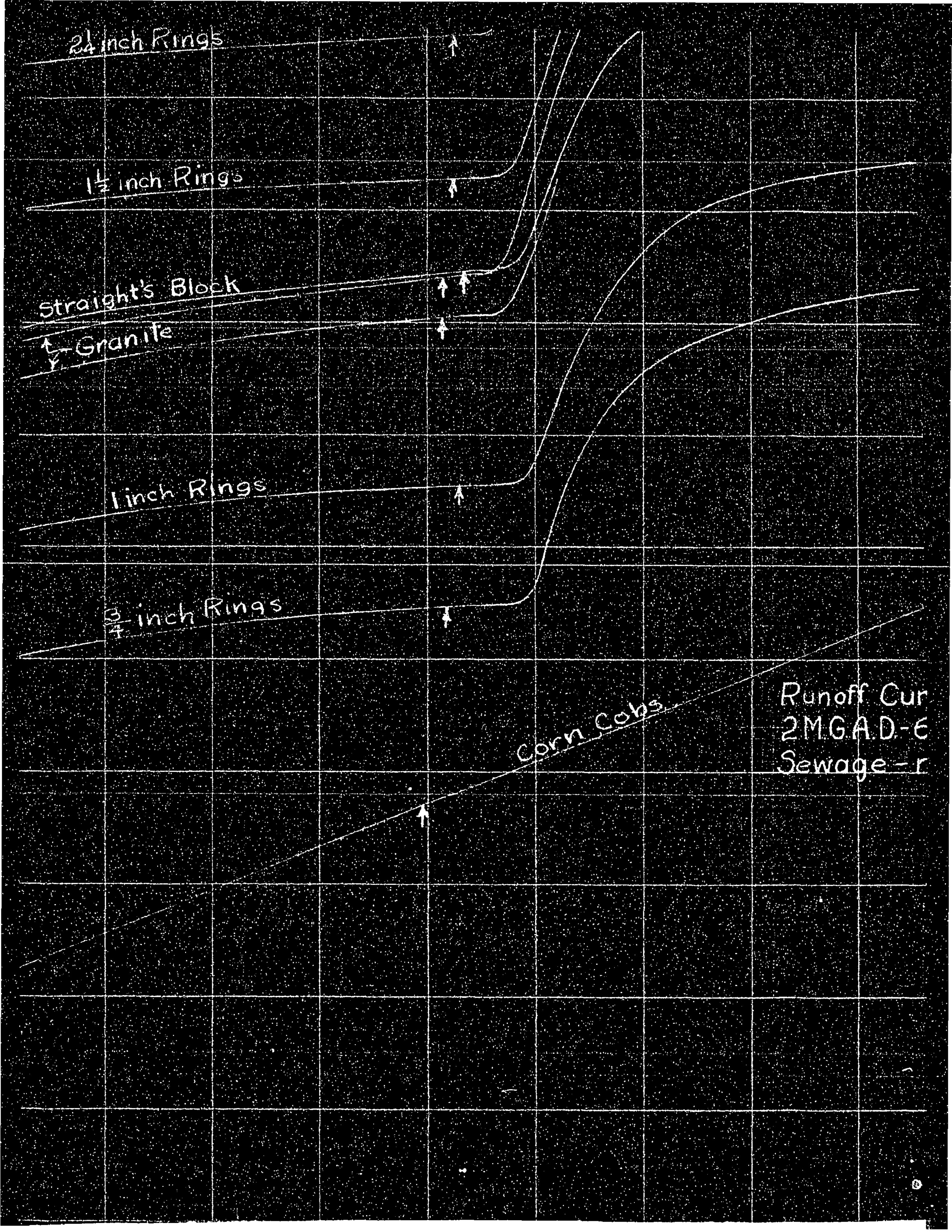
Note: Readings were taken at 10 second intervals. The readings are given in hundredths of a pound. The readings taken on the minute are underlined. The time of application of the dose is indicated by the number in parenthesis.



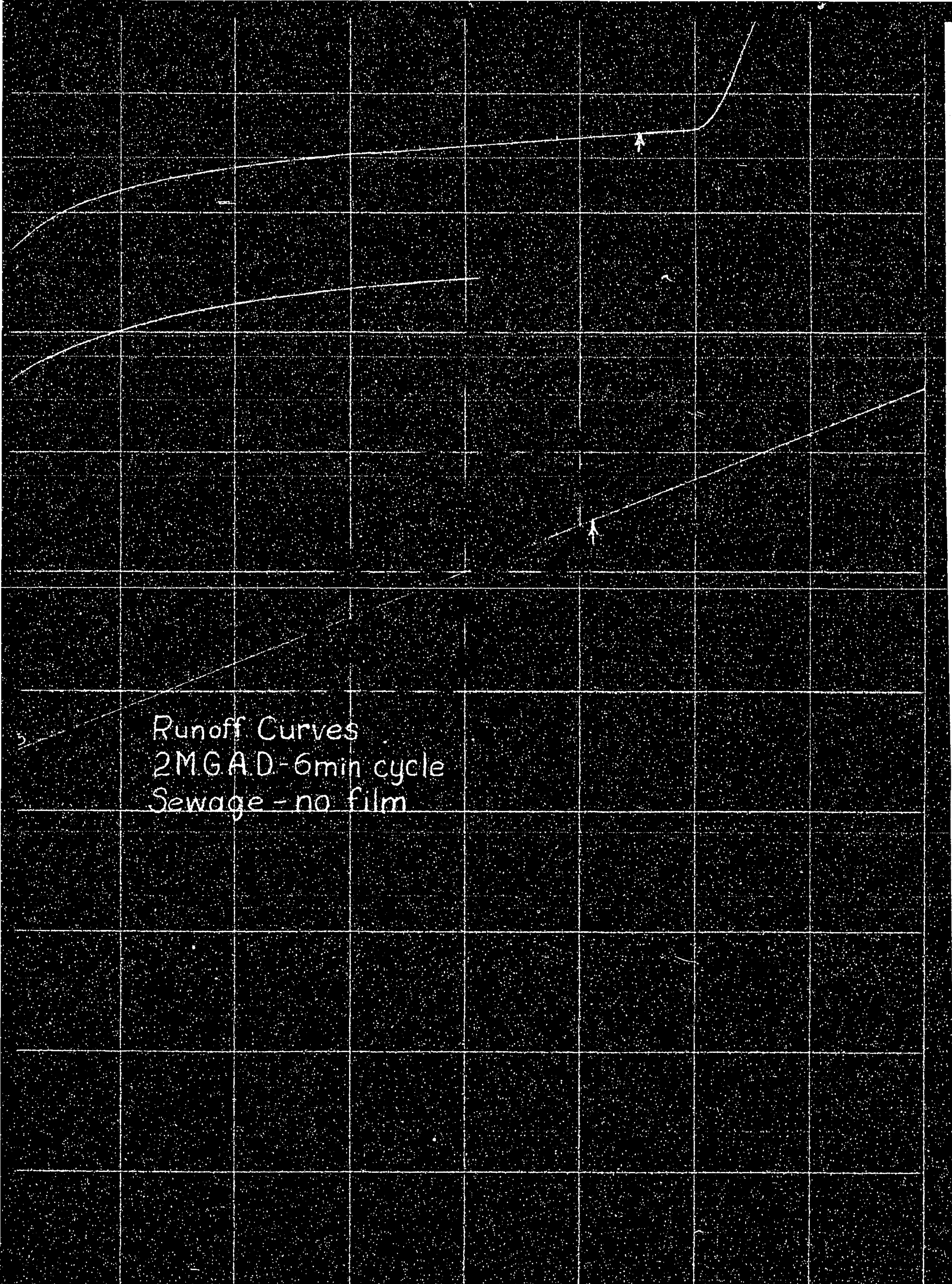
2¼ inch R
1½ inch
Straight's
Granite

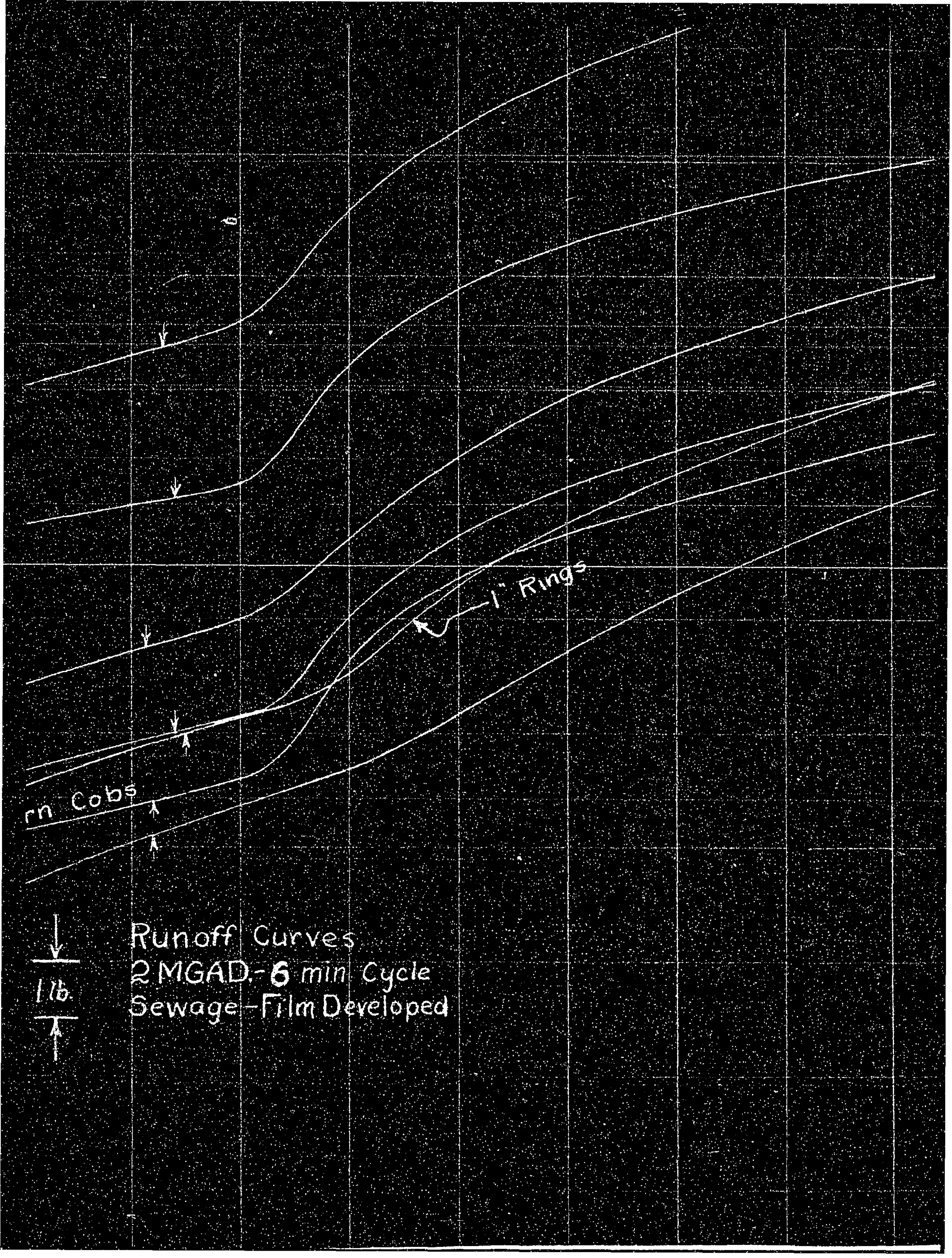


2¼ inch R1
1½ inch F
Straight's B
¼-Granite
1 inch
¾ inch

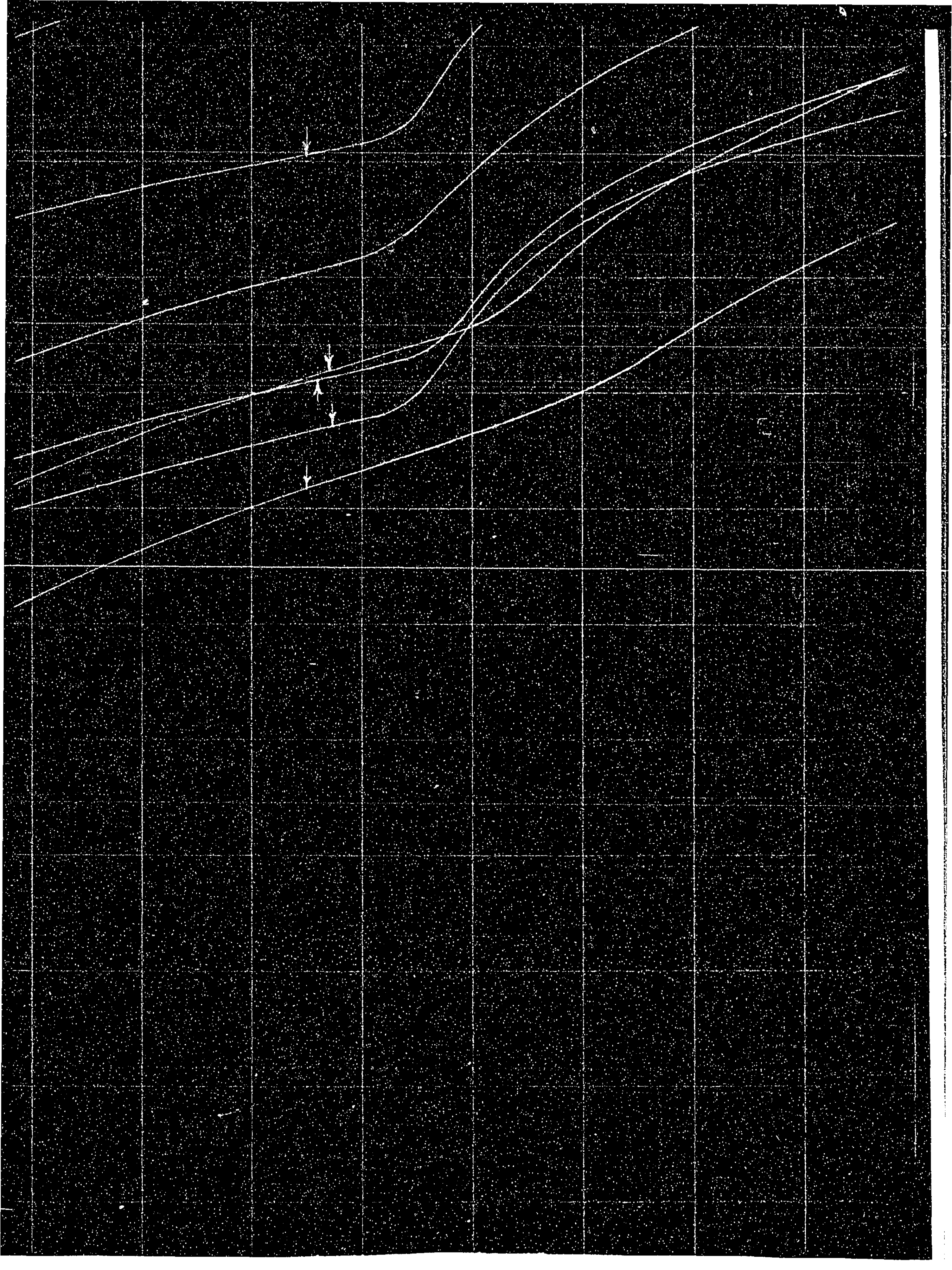


2¼ inch Rings
1½ inch Rings
Straight's Block
¼-Granite
1 inch Rings
¾ inch Rings
Corn Cobs
Runoff Cur
2 M.G.A.D.-6
Sewage - r


Runoff Curves
2 M.G.A.D. - 6 min cycle
Sewage - no film



rn Cobs
1" Rings
1 lb.
Runoff Curves
2 MGAD.-6 min Cycle
Sewage-Film Developed



shown in these three tables are plotted in Fig. (27). The general shape of all the runoff rate curves is the same. After the application of the dose there is a period of lag, during which time the rate continues much as before. Then suddenly the rate increases to a maximum. Following this peak there is a rapid decrease in runoff rate to about 100 per cent of average rate after which the rate more gradually decreases to a minimum. The differences in the shape of the curves are principally in magnitude, although there is a marked difference in the time required to reach a maximum after the application of the dose.

The marked difference in the behavior of the filters when dosed with water as compared with sewage without the film is of interest. In the granite filter the maximum runoff rate of the sewage is about 10 per cent above that of the water, and the time at which the peak occurs is nearly the same. In the case of the 3/4- inch Raschig ring filter the maximum rate with the sewage is nearly double that with the water, and the time after application of the dose at which the peak occurs is about 50 seconds with the sewage as compared with about 75 seconds for the water. In the case of the 1-inch ring filter the difference is less marked, and in the case of the 1 1/2-inch ring filter the difference is of the same order as in the granite. In the case of the 2 1/4-inch ring filter, however, the maximum rate for the water is about 10 per cent higher than for the sewage, although the maximum rate for the water occurs about 10 seconds

Table No.20 Runoff Rate Data. Conditions - 2 M.G.A.D., 6 min cycle, water, no film developed.

Time		RUNOFF RATE - per cent of average flow					
		Granite	Raschig Rings				Straight's
min.	sec.		$\frac{3}{4}$ in.	1 in.	$1\frac{1}{8}$ in.	$2\frac{1}{4}$ in.	Block
	0	34	40	29	19	15	33
	10	34	41	30	19	19	33
	20	35	41	33	21	59	33
	30	88	41	36	42	593	43
	40	279	44	139	616	898	117
	50	468	62	413	624	654	268
1	0	391	154	454	395	388	310
	10	315	299	363	302	224	354
	20	238	298	268	217	140	320
	30	184	257	209	168	120	256
	40	152	226	172	142	98	208
	50	131	201	142	110	82	178
2	0	113	170	123	93	68	147
	10		146	107	90	60	129
	20	89	128	93	84	52	117
	30			82	75	44	
	40	75	108	73	66	38	98
	50			67	59		
3	0	63	92	61	50	35	81
	20	55	84	50	40	29	
	40	50	72	47	32	24	
4	0	45	62	41	26	22	49
	20			37	24	20	
	40			33	23	18	
5	0	35	49	30	22	17	34
	20				21	16	
	40				20	16	
6	0	34	40	29	19	15	33

Note: The runoff rate of the corn cob filter was uniform.

later than that for the sewage. Straight's block again shows a marked difference, the maximum rate for the sewage being about 80 per cent greater than for water; the maximum rate for the sewage occurs about 45 seconds after the time of application in the case of the sewage and about 60 seconds in the case of the water.

This marked difference in the behavior with water and sewage was unexpected. The viscosity of sewage is nearly the same as water, or if anything a little greater. The density of the sewage is also somewhat more, although not substantially so. The temperatures of the sewage (66°F.) and the water (58°F.) were near enough the same to be of no significance. In searching for an explanation of the unexpected runoff data, it was suggested that surface tension may play an important part in determining the nature of the flow through the filters. An investigation was made of the influence of surface tension on the runoff rate. This investigation is reported under "Surface Tension Studies".

The effect of the microbial film on the runoff rate is very pronounced. In the case of the granite, the film apparently reduced the maximum rate to one third as well as delaying the time at which it occurred from about 56 seconds after the dose to about 90 seconds. In the case of the 3/4-inch Raschig rings the effect is even more pronounced. The maximum rate is reduced to almost a fifth, and the time at which it occurred is delayed

Table No.21 Runoff Rate Data. Conditions - 2 M.G.A.D., 6 min. cycle, sewage, no film developed.

Time		RUNOFF RATE - per cent of average flow					
		Granite	Raschig Rings				Straight's
min.	sec.		$\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.	$2\frac{1}{4}$ in.	Block
	0	16	16	14	10	10	18
	10	24			10	12	18
	20	36	15	13	34	185	18
	30	168	35	170	337	708	273
	40	461	457	570	728	662	599
	50	620	582	561	639	524	509
1	0	467	516	436	425	403	403
	10	396	322	333	289	241	275
	20	287	230	258	174	136	194
	30	192	172	192	128	85	148
	40	140	132	148	97	68	117
	50	106	109	111	70	57	100
2	0	82	90	88	48	47	85
	10						
	20	53	64	59	36	32	61
	30						
	40	41	53	43	31	25	47
	50						
3	0	35	42	35	28	20	40
	20	32		32			
	40	29		30			
4	0	26	25	25	20	15	29
	20			24			
	40			19			
5	0	19	21	18	15	13	21
	20						
	40						
6	0	16	16	14	10	10	18

Note: The runoff rate of the corn cob filter was uniform.

from 50 seconds to about 180 seconds after application of the dose. In the other sizes of rings the effect is progressively less as the size of ring increases. The variation in the magnitude of the maximum rates among the various media is much more pronounced with water than with sewage, without the microbial film. With the water, the maximum runoff rate for the 2 1/4-inch rings is nearly three times that of the 3/4-inch rings. With sewage the maximum rate for the 2 1/4-inch rings is only 50 per cent greater than that for the 3/4-inch rings. With the film developed, the maximum rate for the 2 1/4-inch rings is nearly three times that of the 3/4-inch rings.

The runoff rate data have been determined for the rate of 4 M.G.A.D., 3 minute cycle. The data were determined in the same manner as for the rate of 2 M.G.A.D., 6 minute cycle. Table No. 23 shows the runoff data for water without the film, Table No. 24, for sewage without film, and Table No. 25 for sewage with the film developed.

The runoff rate curves obtained from the runoff rate data are shown on Fig. (28). The curves are shown for three conditions: Water and sewage without the film, and sewage with the film developed. These three conditions are shown on each of six filter media. As in the case of the 2 M.G.A.D. rate of application the variations in rate are very much greater without the film than after the film had developed. Also, the maximum runoff rates increased progressively from the smaller media to

Table No.22 Runoff Rate Data.

Conditions: [illegible] cycle, [illegible] develop[illegible]

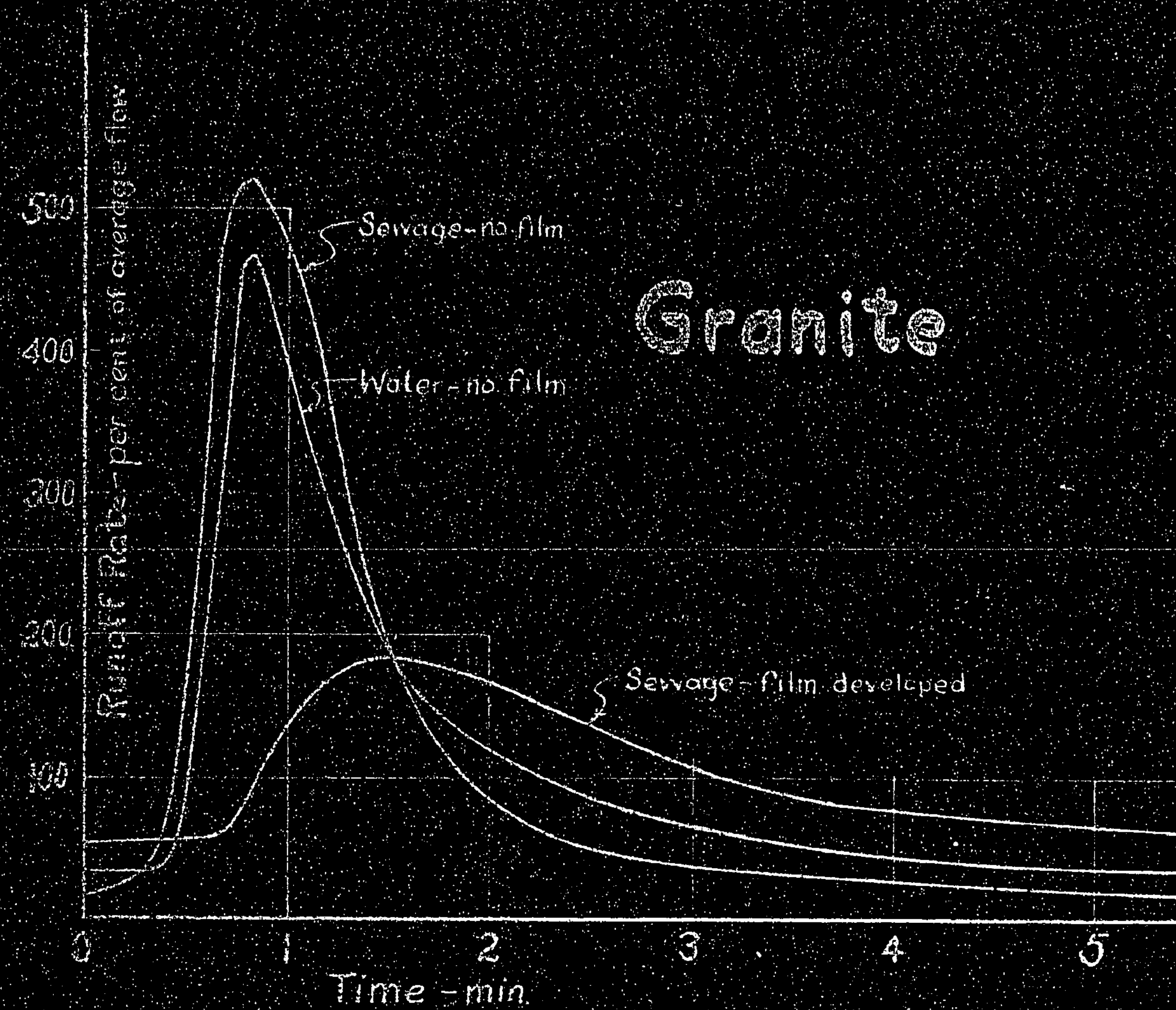
Time		RUNOFF RATE – per cent of average flow						
		Granite	Rasc[illegible] [illegible]				Straight's	Corn
min.	sec.		[illegible] in.	1 in.	1[illegible] in.	2[illegible] in.	Block	Cobs
	0	56	82	[illegible]	57	41	56	51
	10	56	79	[illegible]2	48	43	58	50
	20	57	78	62	42	45	60	52
	[illegible]	57	77	[illegible]2	[illegible]	[illegible]	[illegible]1	82
	40	60	78	62	43	133	76	193
	[illegible]	98	75	62	71	243	130	301
1	[illegible]	136	76	68	181	325	220	321
	10	[illegible]	77	36	244	[illegible]	[illegible]	274
	20	180	78	118	[illegible]	242	219	[illegible]
	[illegible]	[illegible]	87	149	212	[illegible]	185	[illegible]
	[illegible]	175	95	175	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	172	105	174	174	[illegible]	148	137
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	133	[illegible]	[illegible]
	20	[illegible]	127	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	101	121	[illegible]	[illegible]	78	89	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]0	[illegible]	[illegible]0
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]7
[illegible]	[illegible]	[illegible]	[illegible]	85	71	[illegible]	74	61
	[illegible]	[illegible]	[illegible]	57	[illegible]	[illegible]	[illegible]	58
	[illegible]	[illegible]	[illegible]	71	[illegible]	46	53	53
	[illegible]	[illegible]	37	[illegible]	[illegible]	[illegible]	58	52
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41	[illegible]	51

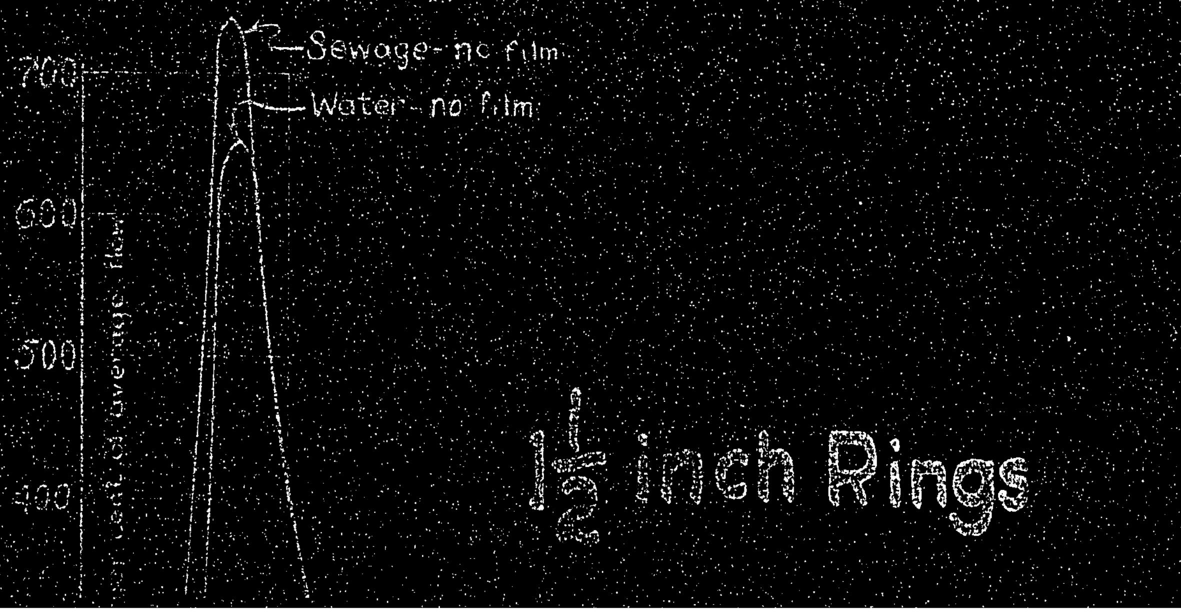
the larger. The variation in maximum rate from smallest size of ring to that of the largest size of ring is not nearly as great, nor are the maximum rates themselves as large as was the case with the 2 M:G.D.A. rate of application. This is especially true of the maximum rates after the film had developed. With the film developed the variations in runoff rates are very small. The unusually high maximum runoff rate for the 3/4-inch rings for sewage without the film is not explained. No irregularity in operation was noted at the time the determination was made.

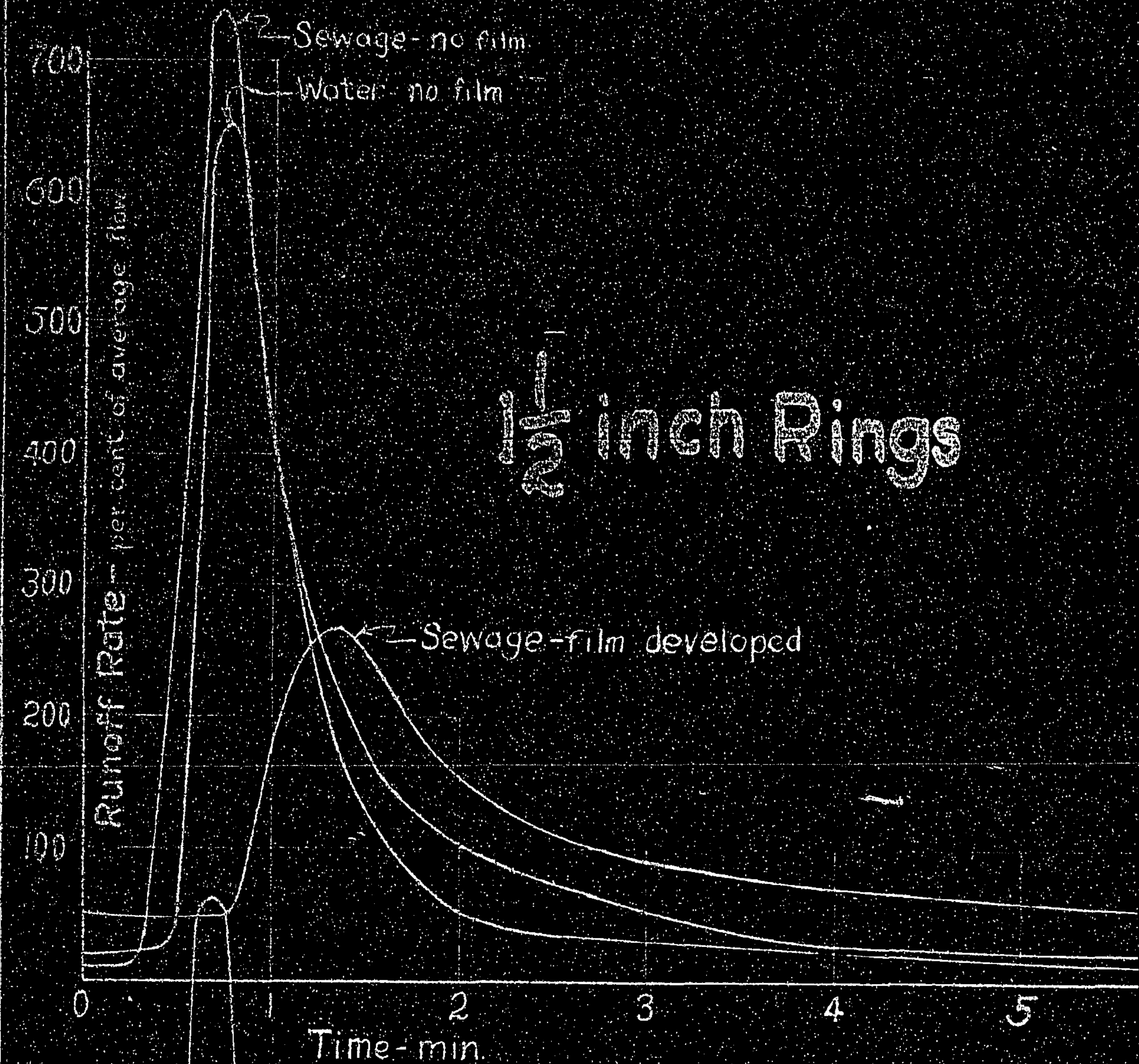
The runoff rate data have been determined for water and sewage without the film at the rate of 2 M.G.A.D., 3 minute cycle, and are shown on Table No. 26. The experimental plant was not operated at this rate long enough to develop a film, thus the runoff rates were not determined with the film developed. The runoff rate curves obtained from the runoff rate data are shown on Fig. 29. These runoff rate curves are quite comparable with those obtained at the rate of 4 M.G.A.D. shown on Fig. 28, except that the maximum rate for water is greater than that for sewage in most cases.

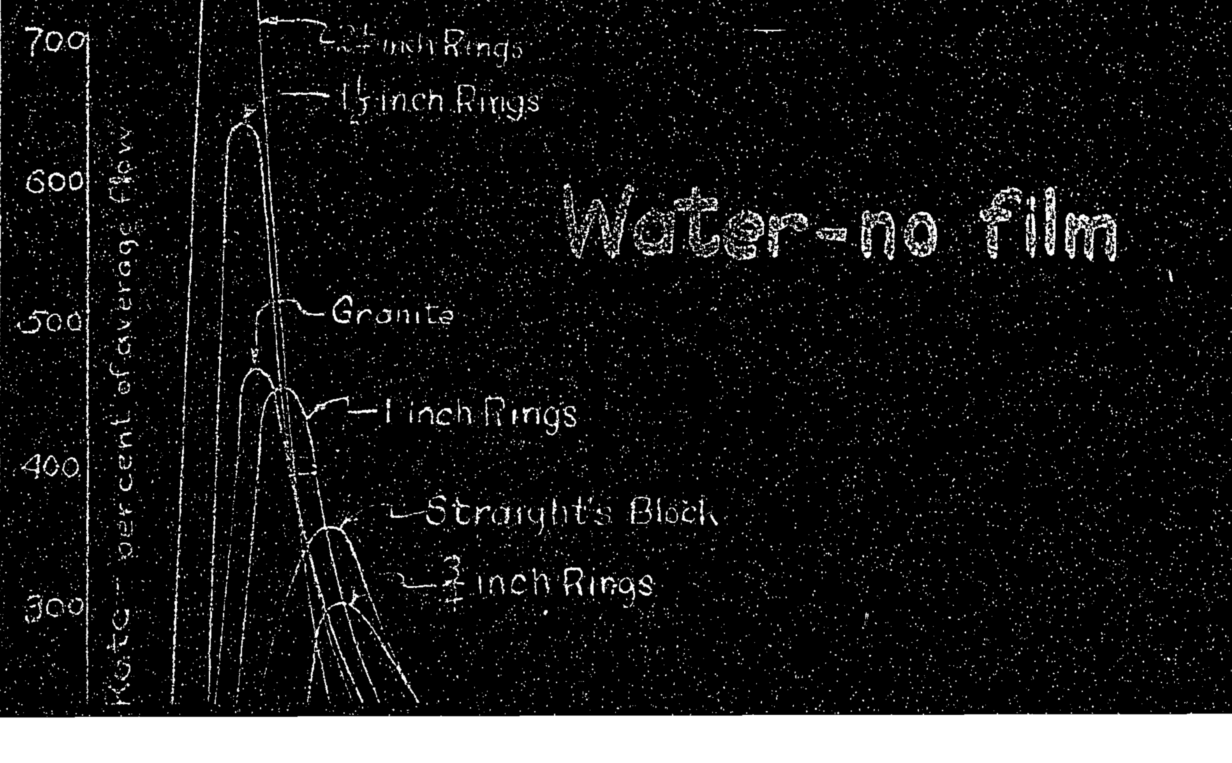
The runoff rate data for the rate of 8 M.G.A.D., 3 minute cycle, with the film developed, are shown on Table No. 27. It is to be noted that the runoff rate from the 3/4 and 1-inch Raschig ring filters varied less than 10 per cent; such a small amount that the accuracy of the method of determination was not great enough to warrant exact figures being given for

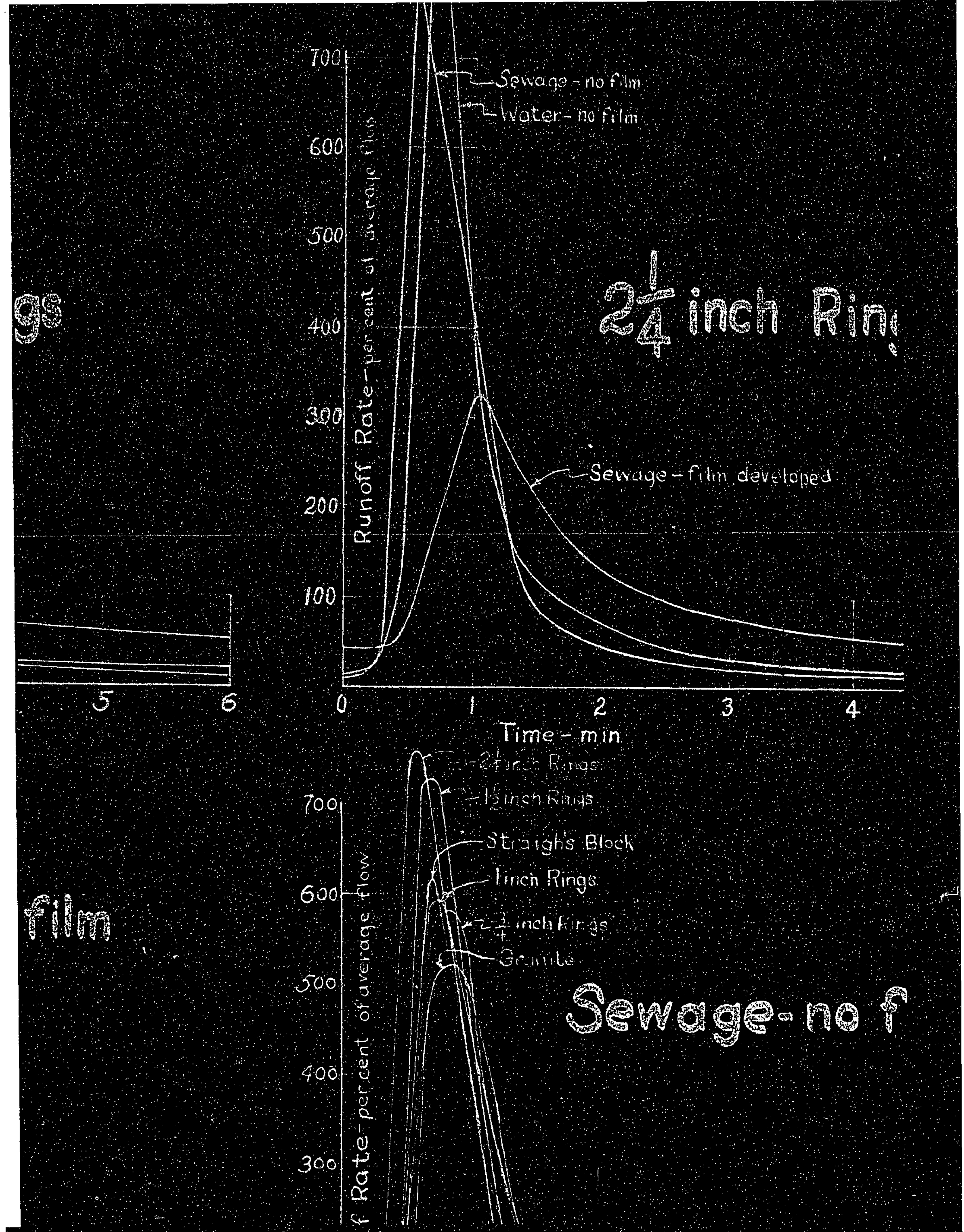
Runoff Rate Curves-



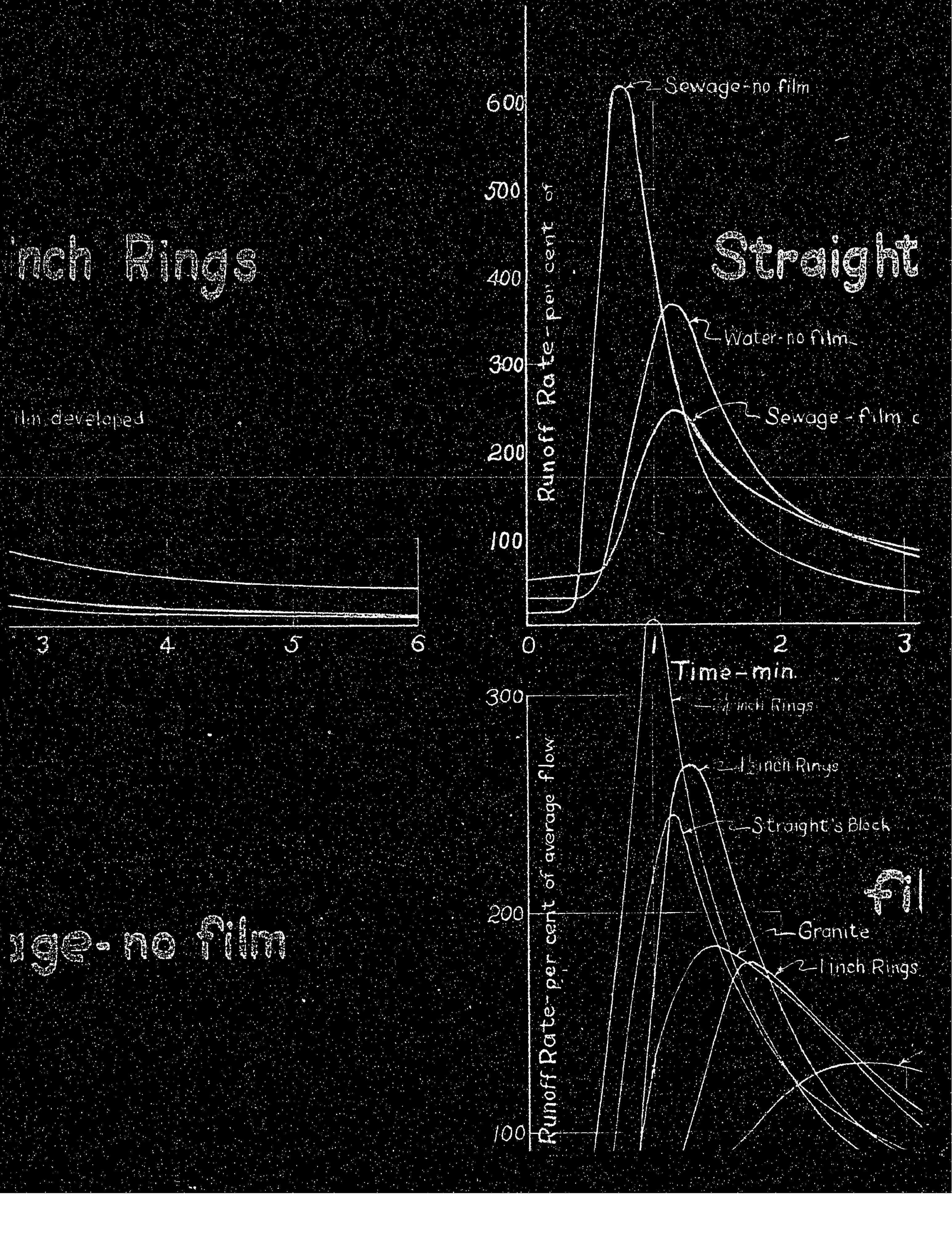



Sewage- no film
Water - no film
1½ inch Rings
Sewage-film developed
Runoff Rate - per cent of average flow
700
600
500
400
300
200
100
0
1
2
3
4
5
Time - min.

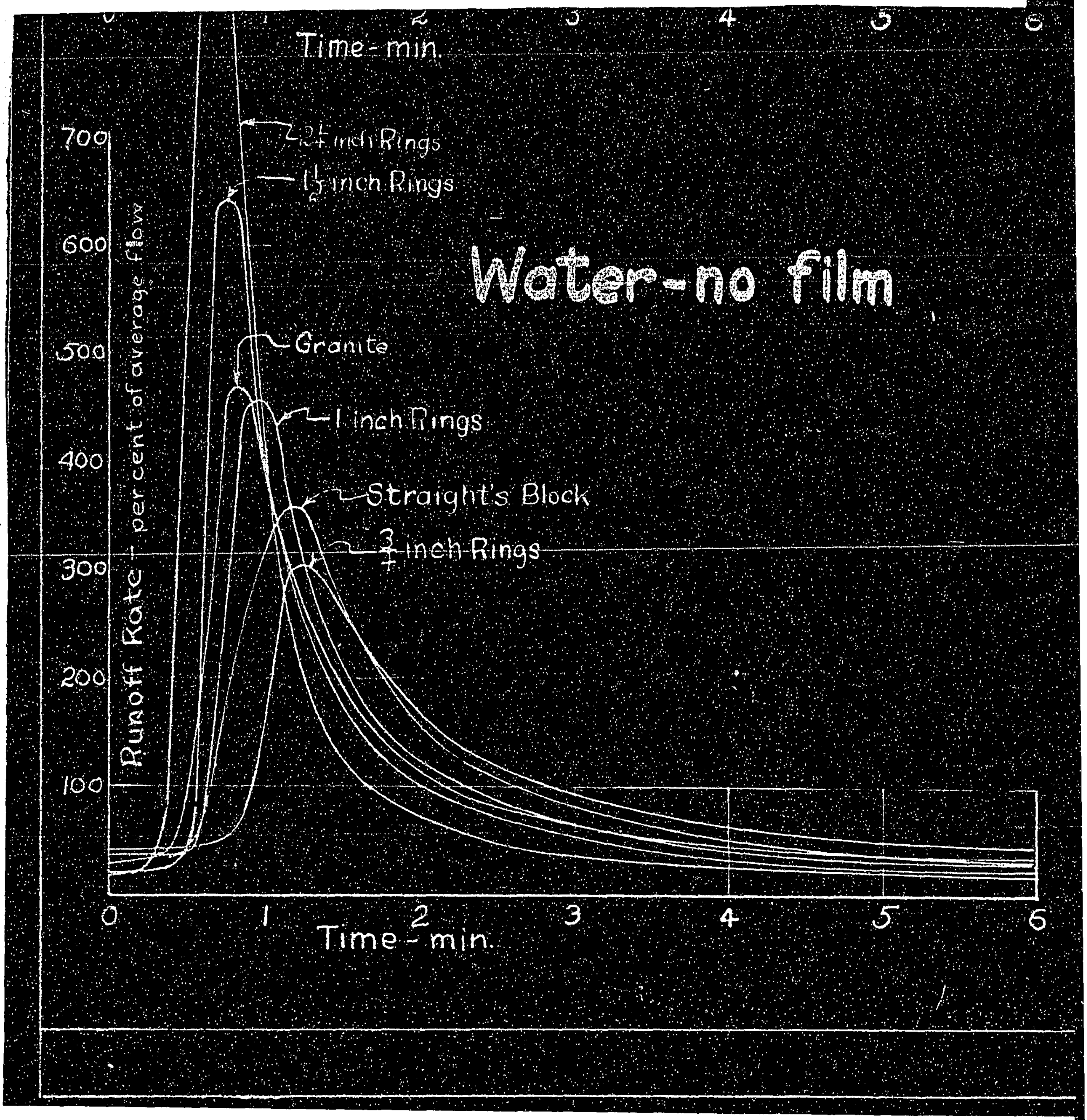

2½ inch Rings
1½ inch Rings
Water-no film
Granite
1 inch Rings
Straight's Block
¾ inch Rings
Rate - per cent of average flow
700
600
500
400
300



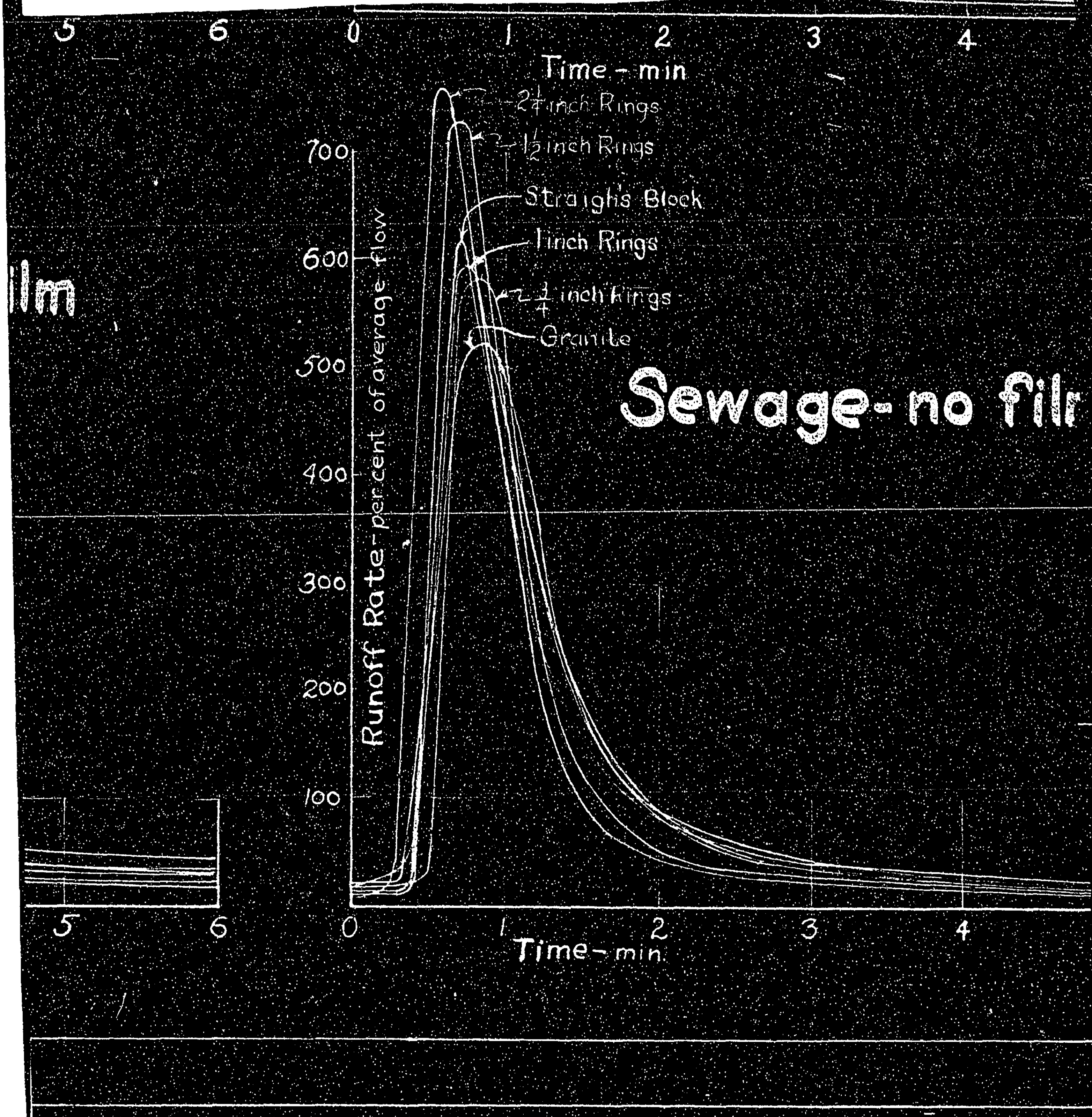
Sewage - no film
Water - no film
Runoff Rate - per cent of average flow
2¼ inch Rin
Sewage - film developed
Time - min
2¼ inch Rings
1½ inch Rings
Straight Block
1 inch Rings
¾ inch Rings
Granite
f Rate - per cent of average flow
Sewage - no f
gs
film



inch Rings
Straight
Sewage-no film
Water-no film
Sewage-film
ilm developed
Runoff Rate-per cent of
Time-min.
inch Rings
inch Rings
Straight's Block
Granite
1 inch Rings
Runoff Rate-per cent of average flow
ge-no film
fil
600
500
400
300
200
100
0
1
2
3
4
5
6
300
200
100



Water-no film
Time-min.
Runoff Rate - per cent of average flow
700
600
500
400
300
200
100
0
1
2
3
4
5
6
Time-min.
$2\frac{1}{4}$ inch Rings
$1\frac{1}{2}$ inch Rings
Granite
1 inch Rings
Straight's Block
$\frac{3}{4}$ inch Rings



Time - min
$2\frac{1}{4}$ inch Rings
$1\frac{1}{2}$ inch Rings
Straight's Block
1 inch Rings
$2\frac{1}{4}$ inch Rings
Granite
Sewage- no filr
ilm
Runoff Rate - per cent of average flow
700
600
500
400
300
200
100
0
1
2
3
4
5
6
Time - min.

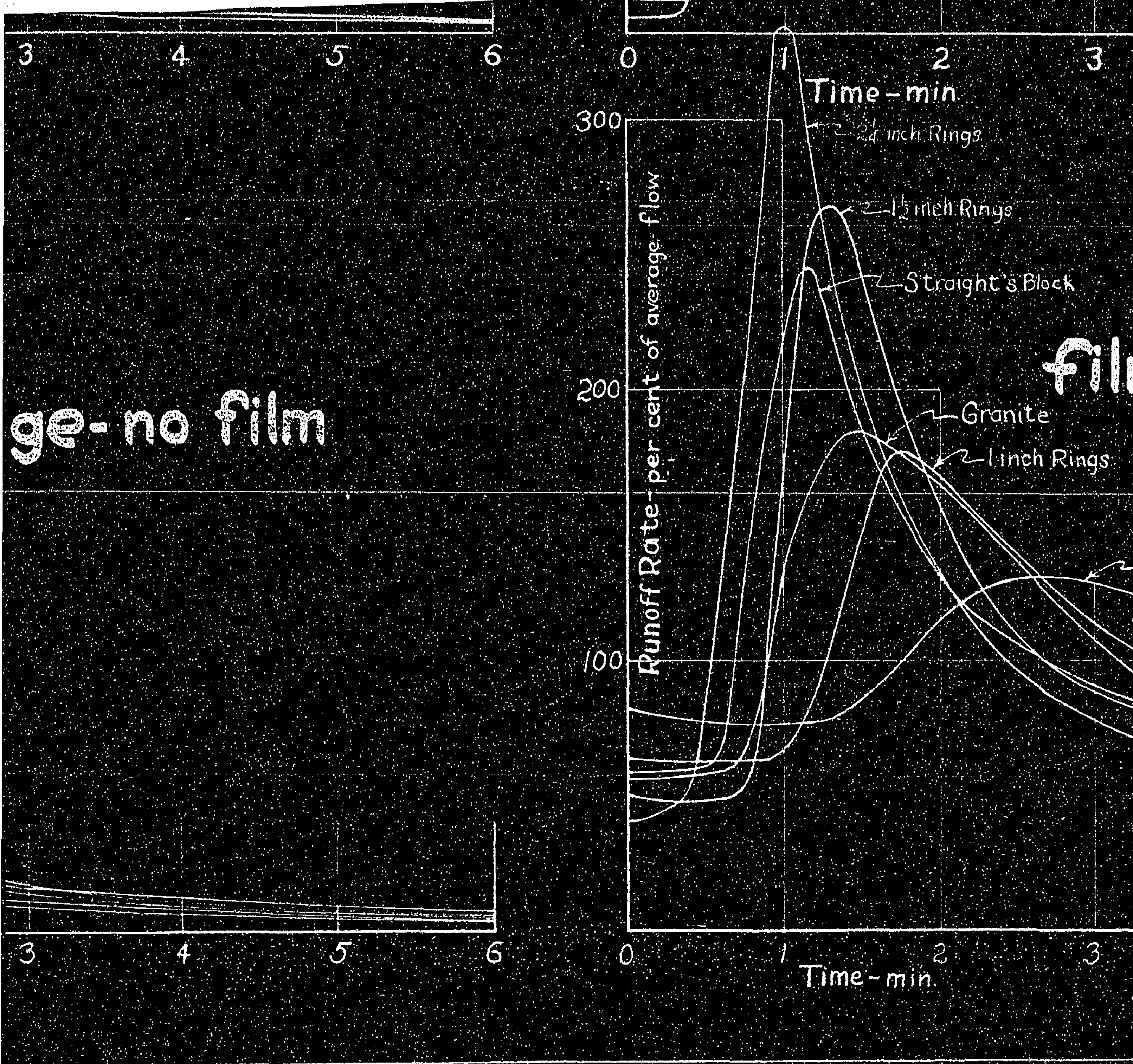

ge-no film
fil
Time - min.
Runoff Rate-per cent of average flow
2¼ inch Rings
1½ inch Rings
Straight's Block
Granite
1 inch Rings
300
200
100
0
1
2
3
4
5
6
Time - min.

Fig. 27 Run

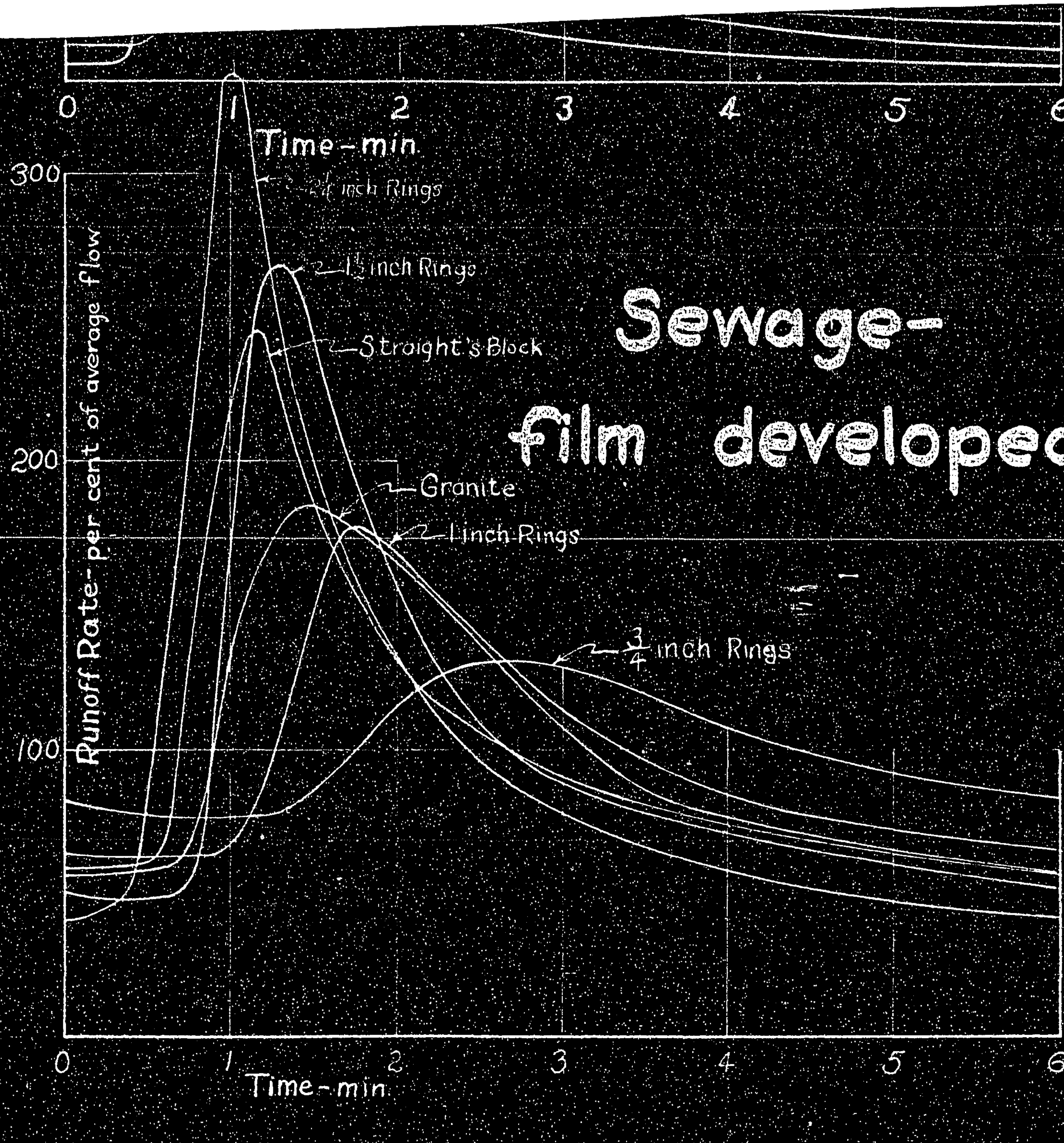


Fig. 27 Runoff Rate Curves - 2M.G.A.D., 6 min. cycle

Table No. 23 [illegible] Da[illegible]

Conditions: [illegible]

Time min. sec.	[illegible]	[illegible] in.	[illegible] in.	1 in.	[illegible] in.	B[illegible]
[illegible]	[illegible]	[illegible]	44	[illegible]	27	[illegible]
[illegible]	[illegible]	4	12	[illegible]	[illegible]	[illegible]
[illegible]	5	[illegible]	40	[illegible]	12[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	3	[illegible]	[illegible]	1
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	1[illegible]	1[illegible]	1[illegible]	13	[illegible]	[illegible]
[illegible]	1[illegible]	[illegible]	[illegible]	87	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	1[illegible]	7	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	72
[illegible]	[illegible]	[illegible]	[illegible]	37	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	31	[illegible]	[illegible]
[illegible]	[illegible]	5	14	[illegible]	17	[illegible]

Note: [illegible]

Table No. 24 Runoff Rate Data.

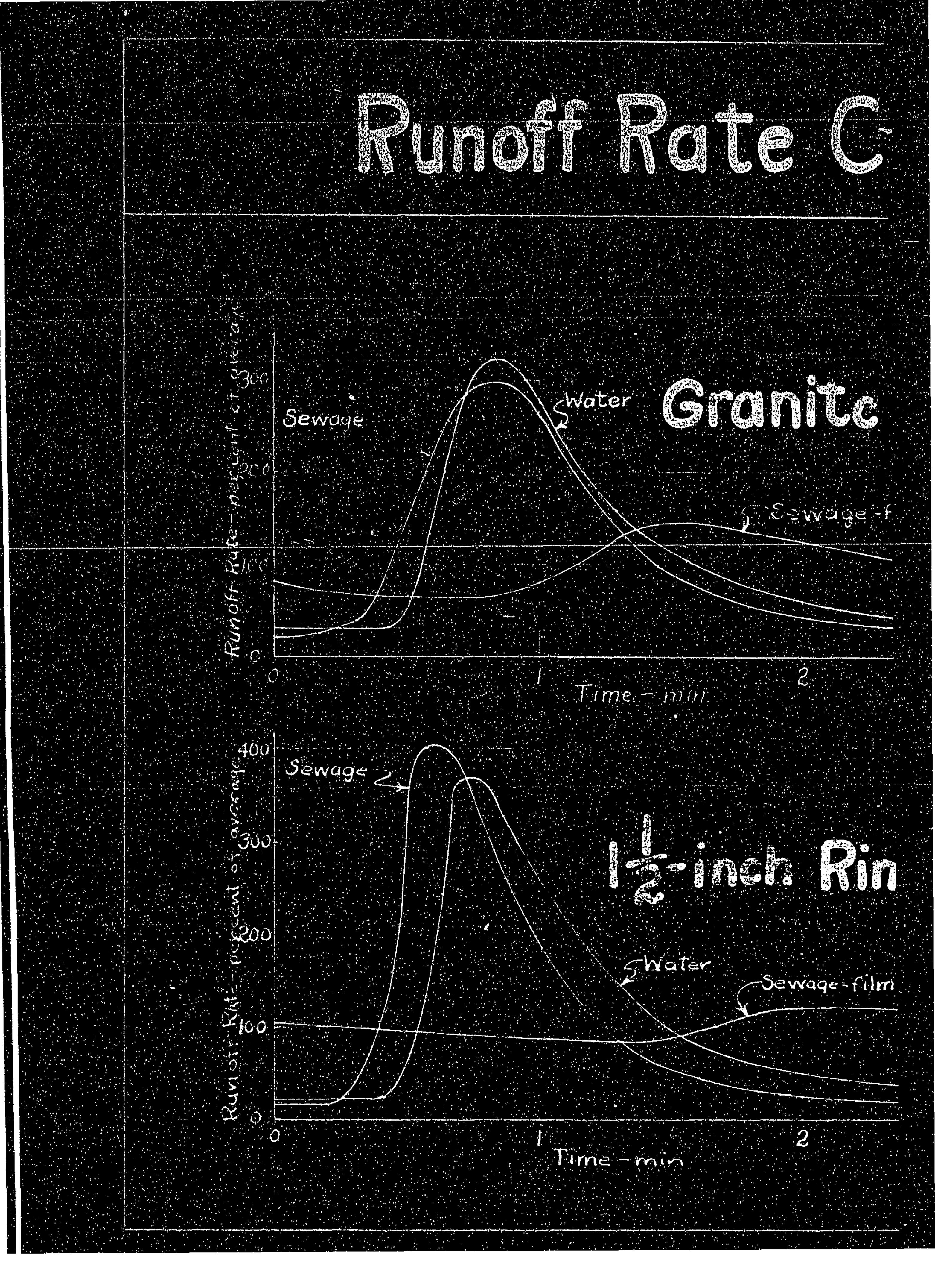
Conditions: [illegible] M.G. [illegible], 3 min. cycl[illegible], sewage, [illegible]nd film.

Time		RUNOFF RATE - per cent of average flow					
		Granite					Strai[illegible]'s
min.	sec.		¾ in.	1 in.	1[illegible] in.	2[illegible] in.	Block
	0	23	22	19	15	14	25
	10	26	21	17	16	13	25
	20	42	20	17	54	170	41
	30	144	197	171	[illegible]	406	106
	40	264	341	526	595	560	381
	50	[illegible]	525	[illegible]	[illegible]	[illegible]	301
1	0	265	221	231	109	16[illegible]	108
	10	169	155	170	16[illegible]	15[illegible]	109
	20	133	107	134	7[illegible]	61	104
	30	92	76	105	[illegible]	49	85
	40	69	60	65	[illegible]	34	72
	50	56	5[illegible]	50	63	26	59
2	0	45	42	45	25	[illegible]	45
	10	37	35	34	40	13	37
	20	31	30	30	[illegible]	21	[illegible]
	30	29	27	25	1[illegible]	1[illegible]	25
	40	26	26	23	17	1[illegible]	25
	50	23	24	21	1[illegible]	1[illegible]	[illegible]
3	0	22	22	19	15	14	25

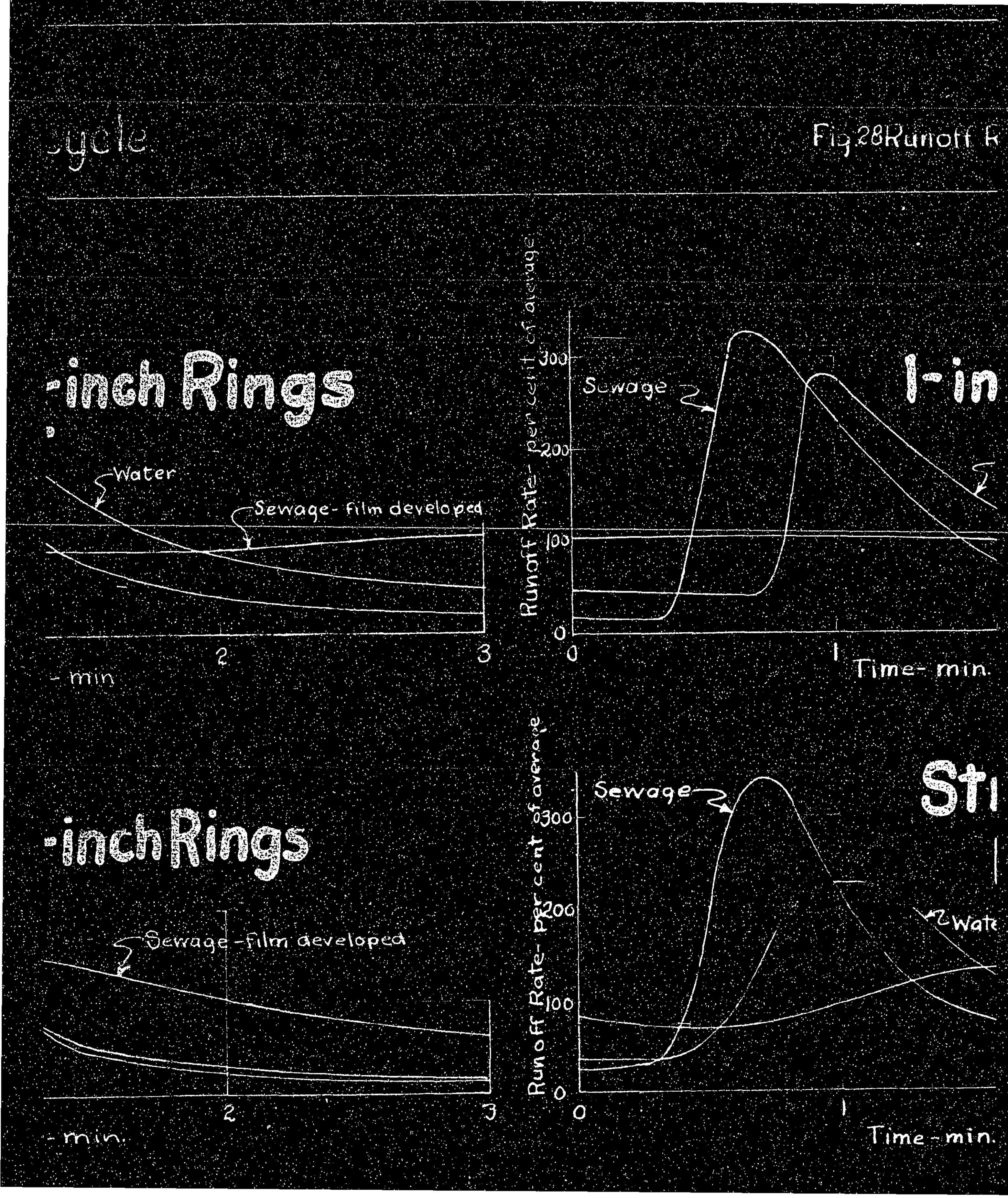
Table No. 25 Runoff Rate Data.

Conditions: 4 M.G.A.D., 3 min. cycle, sewage, film developed.

Time		RUNOFF RATE - per cent of average flow						
		Granite	Rasching Rings				Straight's	Corn
min.	sec.		½ in.	1 in.	1½ in.	2¼ in.	Block	Cobs
	0	81	105		100	63	81	58
	10	73				63	76	57
	20	69				63	73	56
	30	66		105	96	68	70	67
	40	66				89	75	85
	50	65				117	82	114
1	0	81	97		87	146	95	140
	10	103				153	108	155
	20	131				147	123	169
	30	145			86	136	128	149
	40	139			100	128	130	136
	50	135			116	112	127	120
2	0	128	94		120	103	125	106
	10	119				94	118	91
	20	107				86	108	82
	30	99				78	102	75
	40	93				72	95	69
	50	89				66	87	64
3	0	81	104		104	61	81	58



Runoff Rate C
Granite
Sewage
Water
Sewage-f
Runoff Rate - percent of average
0
100
200
300
1
2
Time - min
1½-inch Rin
Sewage
Water
Sewage-film
Runoff Rate - percent of average
0
100
200
300
400
0
1
2
Time - min



cycle.
Fig.28Runoff R
-inch Rings
Water
Sewage- film developed
2
3
- min
Runoff Rate- per cent of average
300
200
100
0
Sewage
0
1
Time- min.
1-in
-inch Rings
Sewage -film developed
2
3
- min.
Runoff Rate- per cent of average
300
200
100
0
Sewage
Wate
0
1
Time - min.
St

the runoff rates.

The runoff rate curves obtained from the above runoff rate data are shown on Fig. (30). These rate curves have a common characteristic, that of a very rapid change in rate from a minimum rate to a maximum rate in a few seconds time. The runoff curves from which these runoff rate curves are calculated have a sharp break at this point. At this point a very marked surge in the flow from the filter occurred. Also to be noted is the marked similarity between the runoff rate curves for the granite, 1 1/2-inch rings and Straight's block. Of these the maximum rate occurs almost simultaneously in the case of the granite and the Straight's block, and then about 20 seconds later in the case of the 1 1/2-inch rings. The 2 1/4-inch rings gave a decidedly greater maximum rate than the 1 1/2-inch rings.

In the operation of a trickling filter the runoff rate with the film developed is of special interest. The runoff rate curves with the film developed, obtained during the three operating periods are shown on Fig. (31). Here are shown the runoff rate curves from the granite, 3/4-inch rings and the 2 1/4-inch rings, for rates of application of 2 M.G.A.D., 6 minute cycle, 4 M.G.A.D., 3 minute cycle and 8 M.G.A.D., 3 minute cycle. The variation in rate is markedly greater in the larger size of ring at all rates of application. The variation in rate is markedly less on the 3/4-inch ring than on granite at all rates of application. The variation in rate is markedly

Table No.26 Runoff Rate Data.

Conditions: 2 M.G.A.D., 3 min. cycle.

Time min.	sec.	RUNOFF RATE - per cent of average fl- Granite	Raschig Rings $\frac{3}{4}$ in.	1 in.	$1\frac{1}{2}$ in.
Water					
	0	55	42	34	26
	10	55	42	33	26
	20	60	42	32	26
	30	213	42	32	297
	40	274	42	75	357
	50	216	294	304	240
1	0	165	295	263	195
	10	125	214	205	141
	20	95	170	160	110
	30	84	126	124	86
	40	72	106	101	73
	50	67	93	85	57
2	0	62	80	71	43
	20	58	67	55	32
	40	55	53	44	28
3	0	55	42	34	26
Sewage					
	0	41	43	32	31
	10	47	43	30	32
	20	81	44	29	33
	30	135	46	29	191
	40	294	175	48	345
	50	223	198	194	316
1	0	165	230	290	27
	10	125	190	232	155
	20	106	147	185	[illegible]
	30	89	118	140	85
	40	77	[illegible]	110	68
	50	70	93	94	57
2	0	64	76	82	50
	20	52	61	60	38
	40	45	46	46	30
3	0	41	45	[illegible]	31

FIG. 29 Runoff Rate Curves - 2 M.G.A.D., 3 min. cycle
no film, water and sewage.

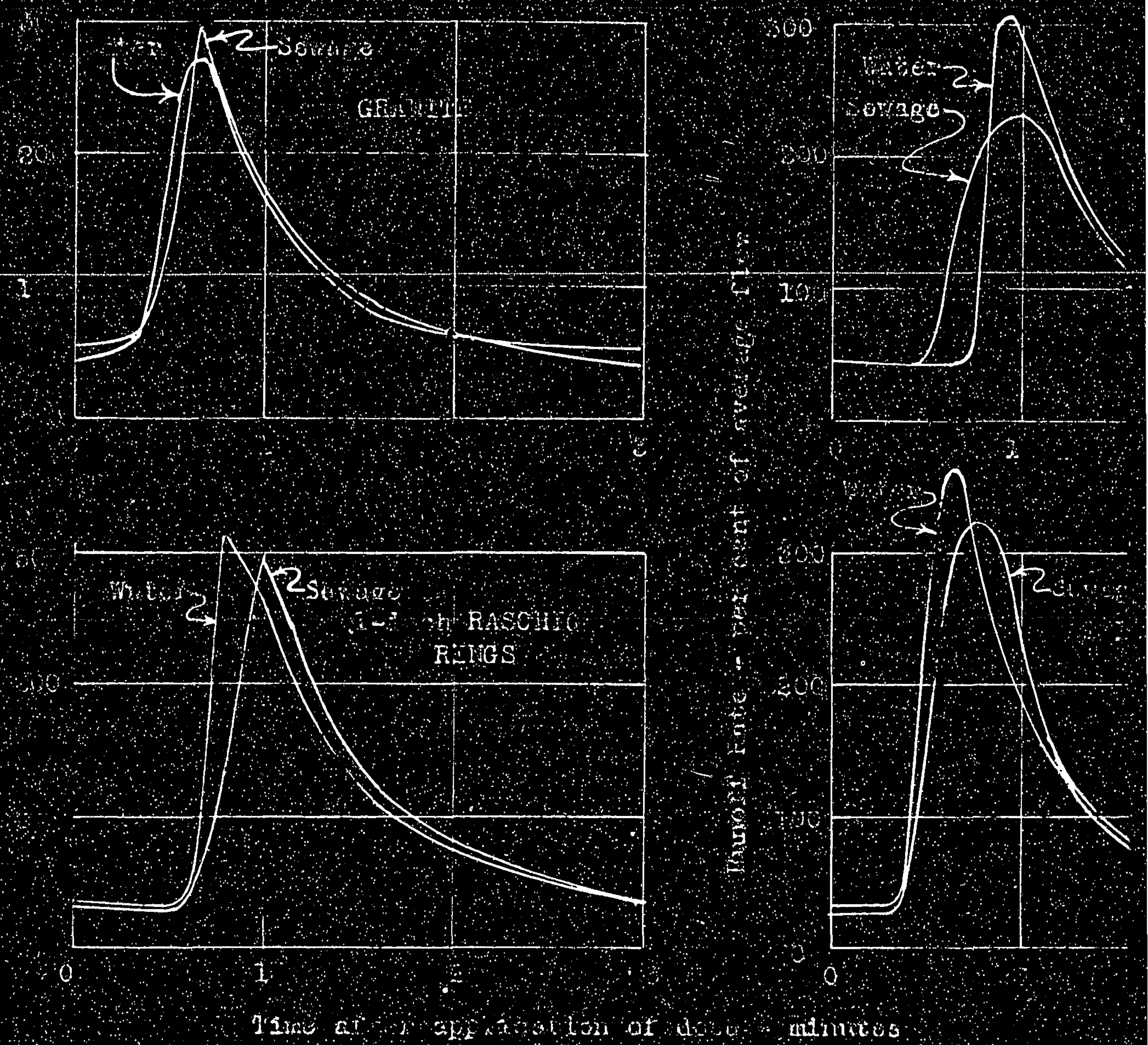


Fig. 29 Runoff Rate Curves - 2 M.G.A.D., 3 min. cycls, no film, water and sewage.

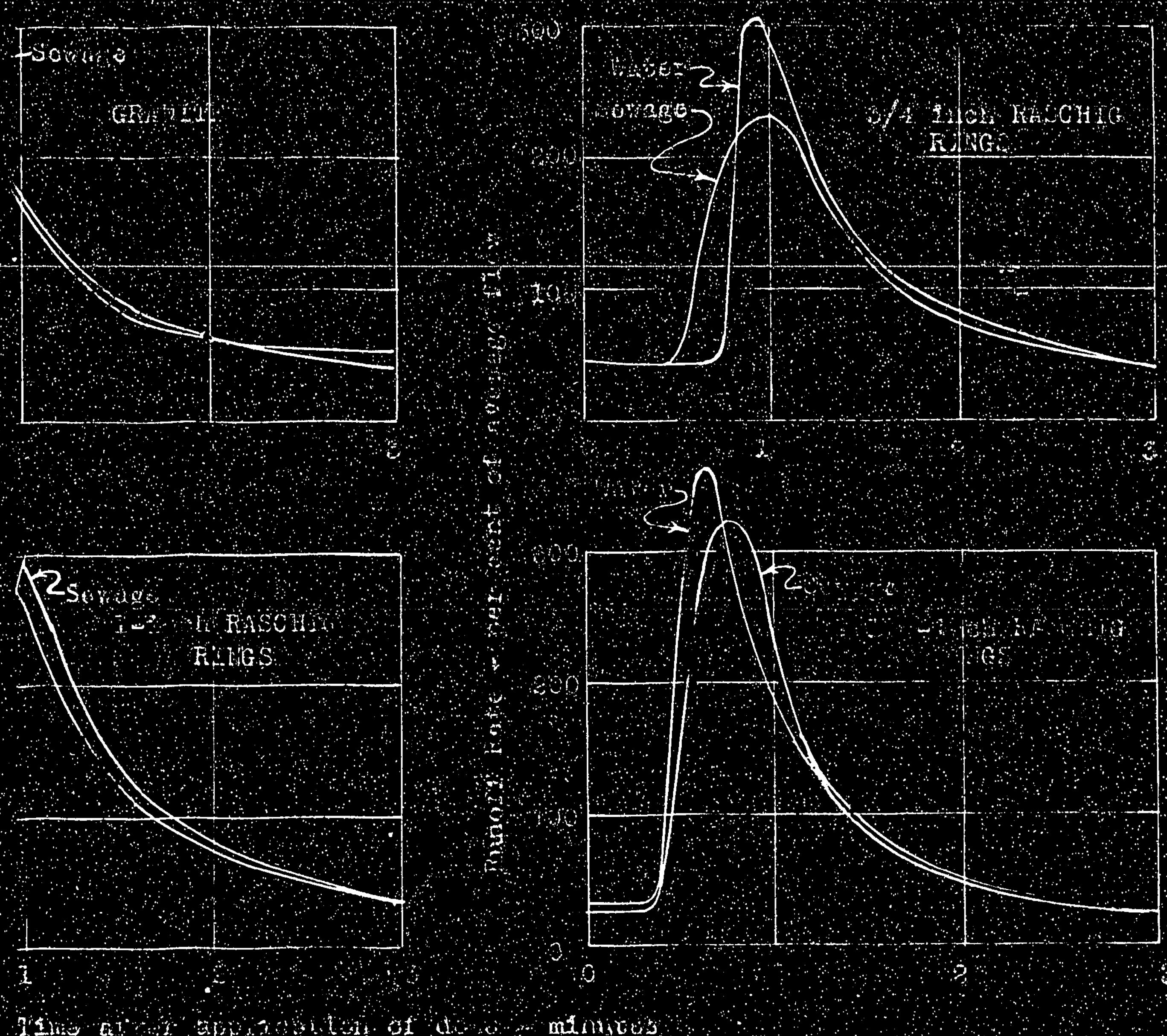
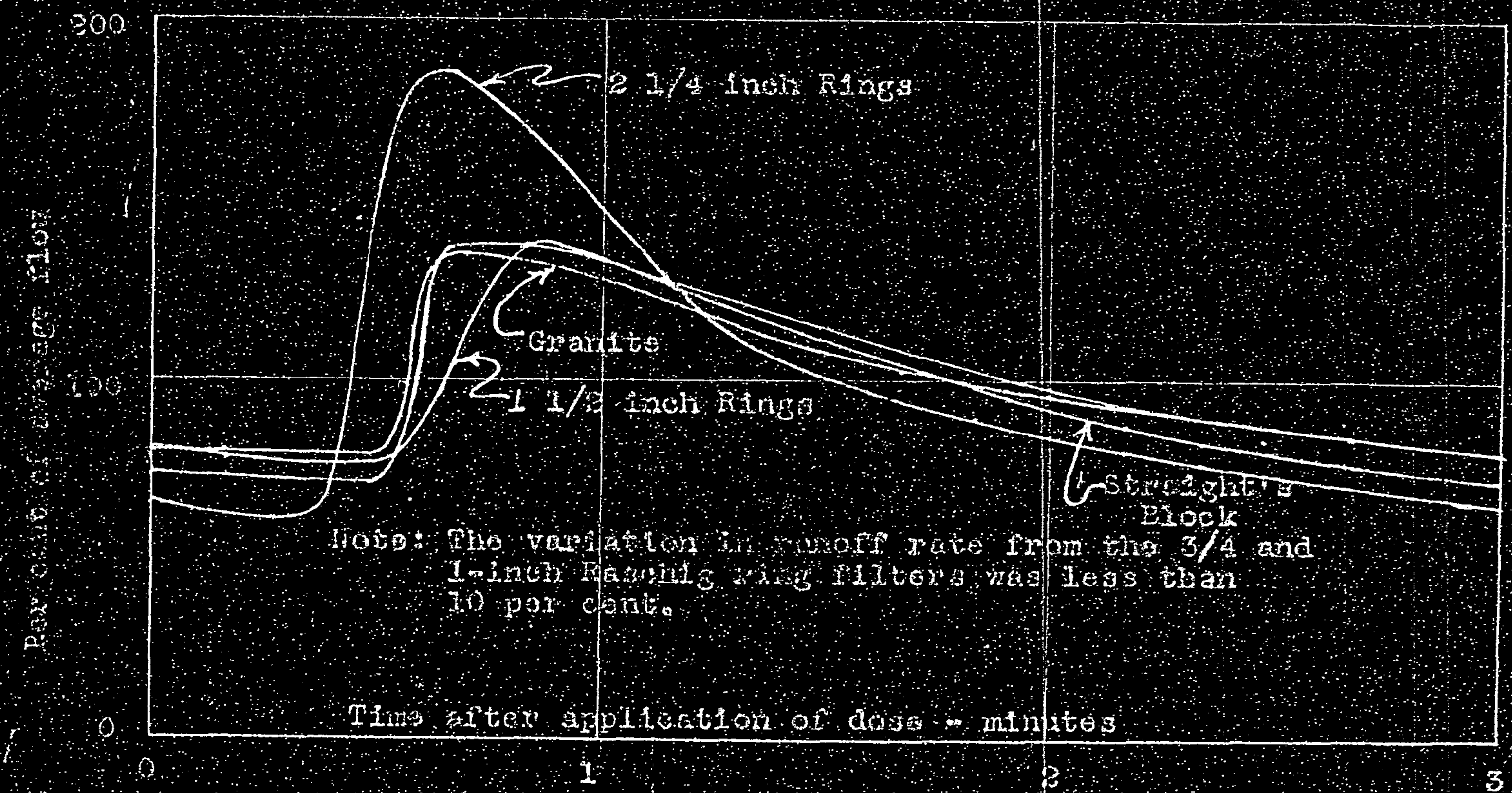


Table No. 27 Runoff Rate Data.
Conditions: 8 M.G.D., 3 min. cycle, sewage, film developed.

Time		RUNOFF RATES - per cent of average flow			
		Granite	Raschig Rings		Straight's
min.	sec.		1½ in.	2¼ in.	Block
	0	80	80	65	73
	10	80	78	62	73
	20	79	77	61	72
	30	79	77	158	72
	40	134	104	188	138
	50	132	138	168	137
1	0	127	133	149	[illegible]
	10	118	125	122	126
	20	114	115	109	119
	30	107	111	99	112
	40	102	108	96	108
	50	99	104	89	98
2	0	96	98	85	90
	10	93	93	80	87
	20	91	91	77	82
	30	87	87	74	76
	40	84	85	71	74
	50	82	82	68	73
3	0	80	80	65	73

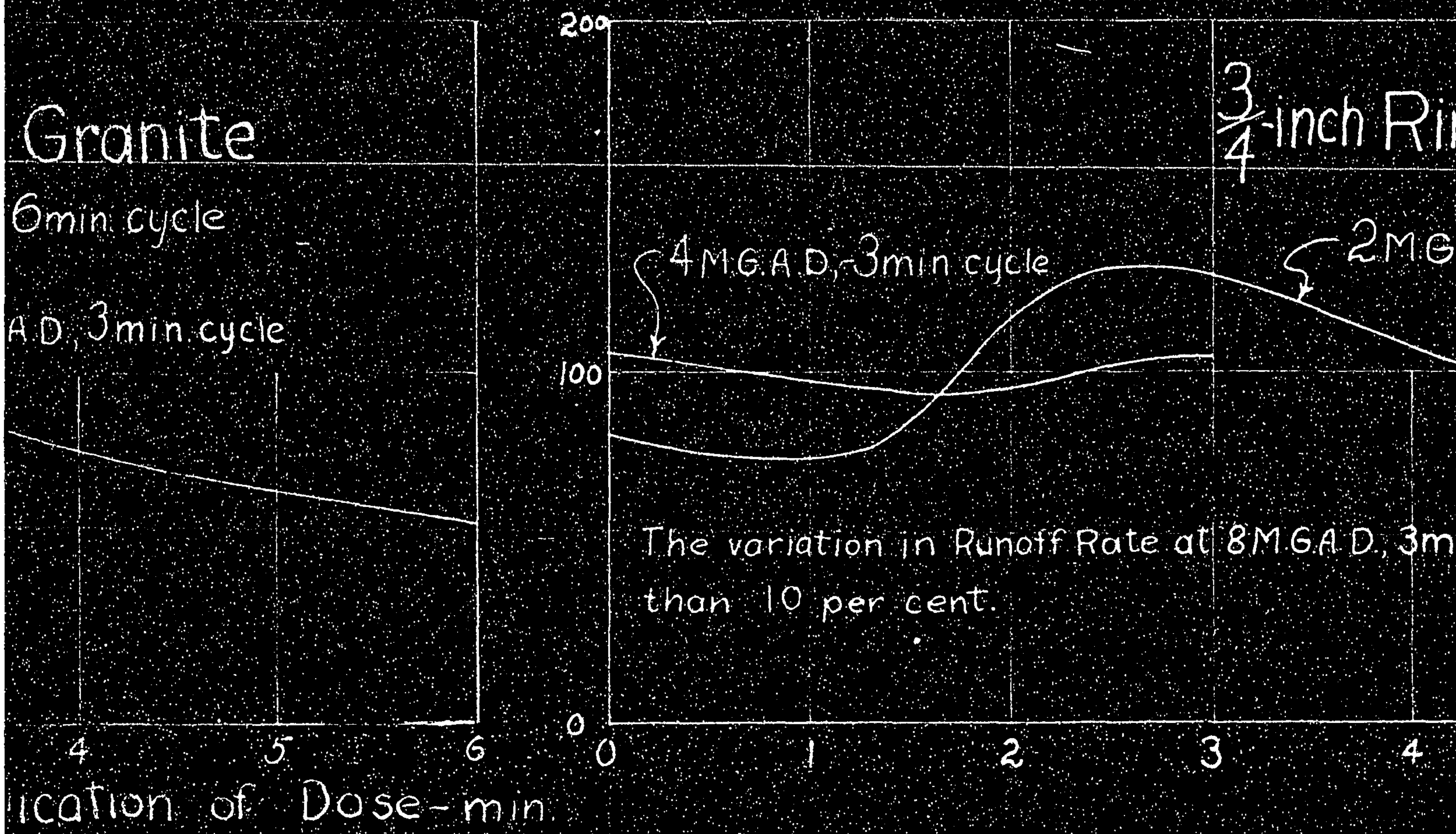
Note: The variation in runoff rate from the ¼ and 1-inch Raschig Ring filters was less than 10 per cent.

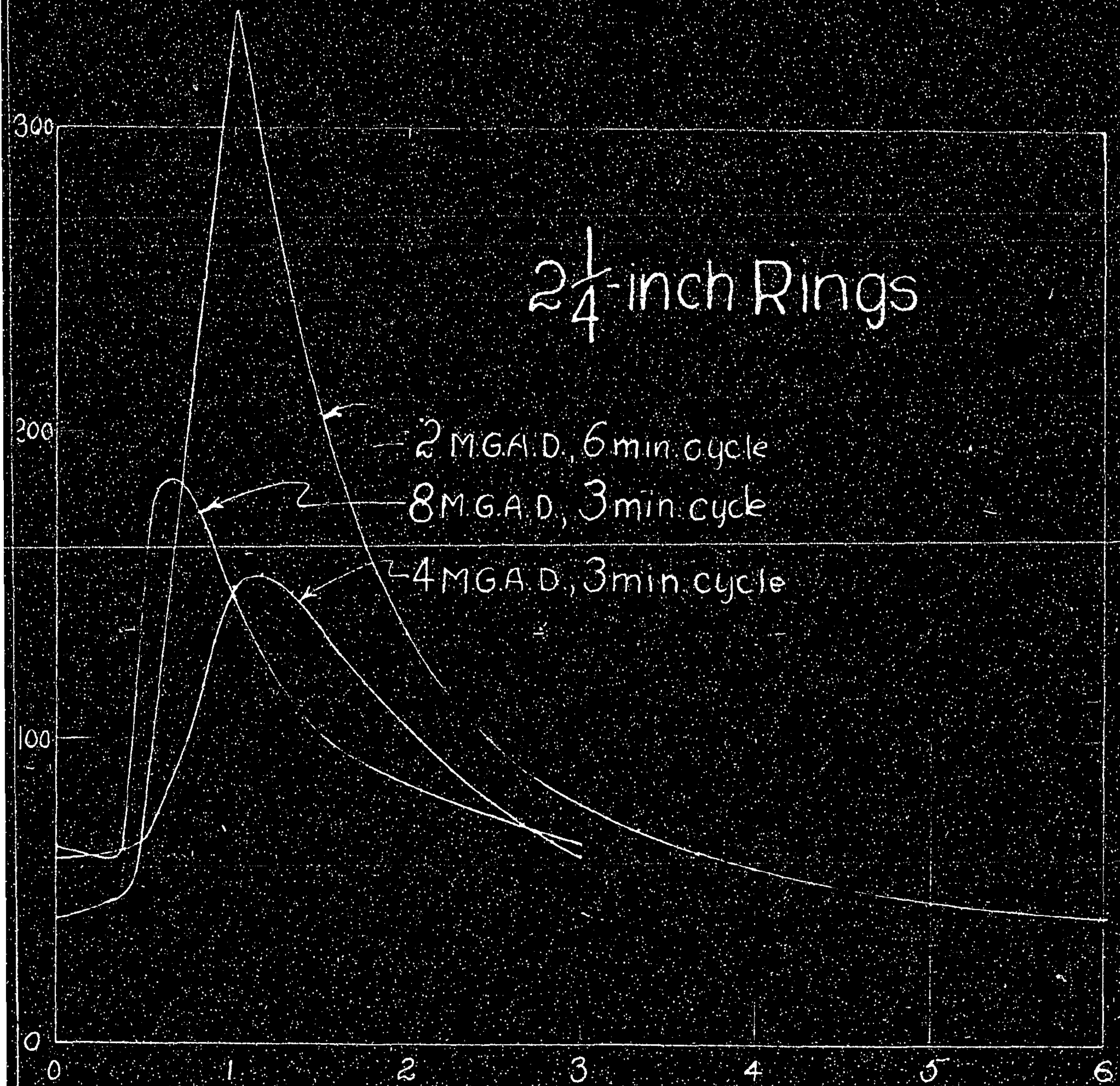
Fig. 30 Runoff Rate Curves - 3 M.G.A.D., 3 min. cycle sewage, film developed



ves obtained during

eriods—film developed




2 1/4-inch Rings
2 M.G.A.D., 6 min. cycle
8 M.G.A.D., 3 min. cycle
4 M.G.A.D., 3 min. cycle
300
200
100
0
0
1
2
3
4
5
6

less for the shorter dosing cycle on all filters. It is possible that inasmuch as the variation for the 3 minute cycle is markedly less than that for the 6 minute cycle, an even shorter cycle would be advantageous.

2. Surface Tension Studies.

An investigation was made (6) of the effect of surface tension on the runoff rate from a 6-inch stoneware tower packed with 3/4-inch Raschig rings. The depth of the tower was 6 feet. The liquid was applied to the upper surface of the medium by means of a perforated metal distributing tray much the same as in the experimental filters, although at a higher rate. Recent work by Baker, Chilton and Vernon (4) indicates that a 6-inch absorption tower is about as small a tower as can be used and still retain "normal" distribution throughout the depth of the bed, and not have undue distribution at the walls of the tower. These workers used a water rate of 500 lbs. per sq. ft. per hr. which corresponds to about 62 M.G.A.D. These workers suggest that the results obtained on this size of absorption tower may be safely translated to conditions in full size absorption equipment.

In order to determine the effect of surface tension the runoff rate of water was compared with that of a liquid having a very different surface tension, but otherwise very like water, using the above described tower. A very dilute soap solution was used as the liquid for comparison with water. The surface tension of water was 71.4 dynes per centimeter as compared with 29.0 dynes per centimeter for the soap solution. The surface tension determinations were made with the du Noüy surface tension apparatus.

The comparative runoff rate data for water and soap solution for both 2 and 4 M.G.A.D. and for both 3 and 6 minute cycles are given in Tables No. 28 and 29.

A comparison of the runoff rate data obtained on the stoneware tower and similar data obtained on the experimental filters is shown in Figs. 32, 33, 34, and 35. Observation of these curves indicates that there is a very marked variation in runoff rate due to surface tension, but that the variation between water and sewage in the experimental filter is greater than between water and soap solution in the stoneware tower, even though the surface tension of the soap solution deviates more from that of water than sewage does. It is entirely possible that this unexpected result is due to "abnormal" distribution in the stoneware tower, since very much lower rates of application were used in this investigation than are customarily used in absorption tower practice, or were used by Baker, Chilton and Vernon (4). To summarize, it may be said that surface tension has a very great effect on the runoff rate from a trickling filter; however, there is still a question as to whether surface tension explains the difference between the runoff rates for sewage and water in the experimental filters

Table No. 28 Runoff Rate Data for Stoneware Tower Packed with $\frac{3}{4}$ inch Raschig Rings.

3 min. cycle

		Runoff Rate - per cent of average flow			
		2 M.G.A.D.		4 M.G.A.D.	
min.	sec.	Water	Soap Solution	Water	Soap Solution
	0	36	36	[illegible]	39
	10	47	41	41	36
	20	[illegible]	[illegible]	46	[illegible]
	30	74	67	115	31
	40	94	96	232	152
	50	[illegible]	135	246	261
1	0	116	[illegible]	179	241
	10	168	[illegible]	149	192
	20	159	183	126	161
	30	146	160	[illegible]	[illegible]
	40	[illegible]	137	94	34
	50	115	114	83	[illegible]
	0	105	101	74	74
	10	97	[illegible]	68	[illegible]
	20	88	79	61	[illegible]
	30	80	[illegible]	[illegible]	51
	40	76	[illegible]	[illegible]	47
	50	[illegible]	[illegible]	[illegible]	44
3	0	[illegible]	[illegible]	[illegible]	[illegible]

Surface Tension

Water - 71.4 dynes per centimeter
Soap Solution - [illegible] dynes per centimeter

T[illegible] No.29 Runoff [illegible] Da[illegible] S[illegible]
[illegible] $\frac{?}{4}$ [illegible]

[illegible]

Time		Runoff Rate - per cent of average flow			
		2 M.C.[illegible]		[illegible] M.G.A.D.	
		Water	Soap Solution	Water	S[illegible]
min.	sec.				
	0	32	1[illegible]	31	9
	10	56	13	31	9
	20	91	1[illegible]	53	[illegible]
	30	1[illegible]	1[illegible]	34	[illegible]
	40	1[illegible]5	3[illegible]	593	[illegible]10
	50	239	1[illegible]1	3[illegible]4	40[illegible]
1	0	[illegible]	408	284	2[illegible]
	10	[illegible]53	3[illegible]	[illegible]3	[illegible]1[illegible]
	20	[illegible]	[illegible]7[illegible]	[illegible]75	169
	30	1[illegible]1	[illegible]1[illegible]	1[illegible]	13[illegible]
	40	167	1[illegible]1	1[illegible]	1[illegible]
	[illegible]	149	1[illegible]	[illegible]51	[illegible]
	[illegible]	130	[illegible]11	[illegible]	[illegible]
	1[illegible]	[illegible]	[illegible]	7[illegible]	[illegible]
	[illegible]	1[illegible]7	[illegible]	58	[illegible]5
	[illegible]	[illegible]	[illegible]	60	48
	40	9	[illegible]	[illegible]6	[illegible]
	50	[illegible]	[illegible]	49	3[illegible]
3	[illegible]	79	4	45	34
	[illegible]	[illegible]	6	44	[illegible]
	4[illegible]	[illegible]	10	36	[illegible]
4	[illegible]	6	5[illegible]	33	[illegible]
	[illegible]	5	1	31	1[illegible]
	40	[illegible]	[illegible]7	2[illegible]	[illegible]
	[illegible]	5	[illegible]1	[illegible]	1
	20	11	1[illegible]	26	11
	[illegible]	[illegible]	1[illegible]	4	[illegible]
	[illegible]	[illegible]	7	[illegible]1	[illegible]

Surface Tension

Water - 71.1 [illegible]
S[illegible] S[illegible] - [illegible] . [illegible]

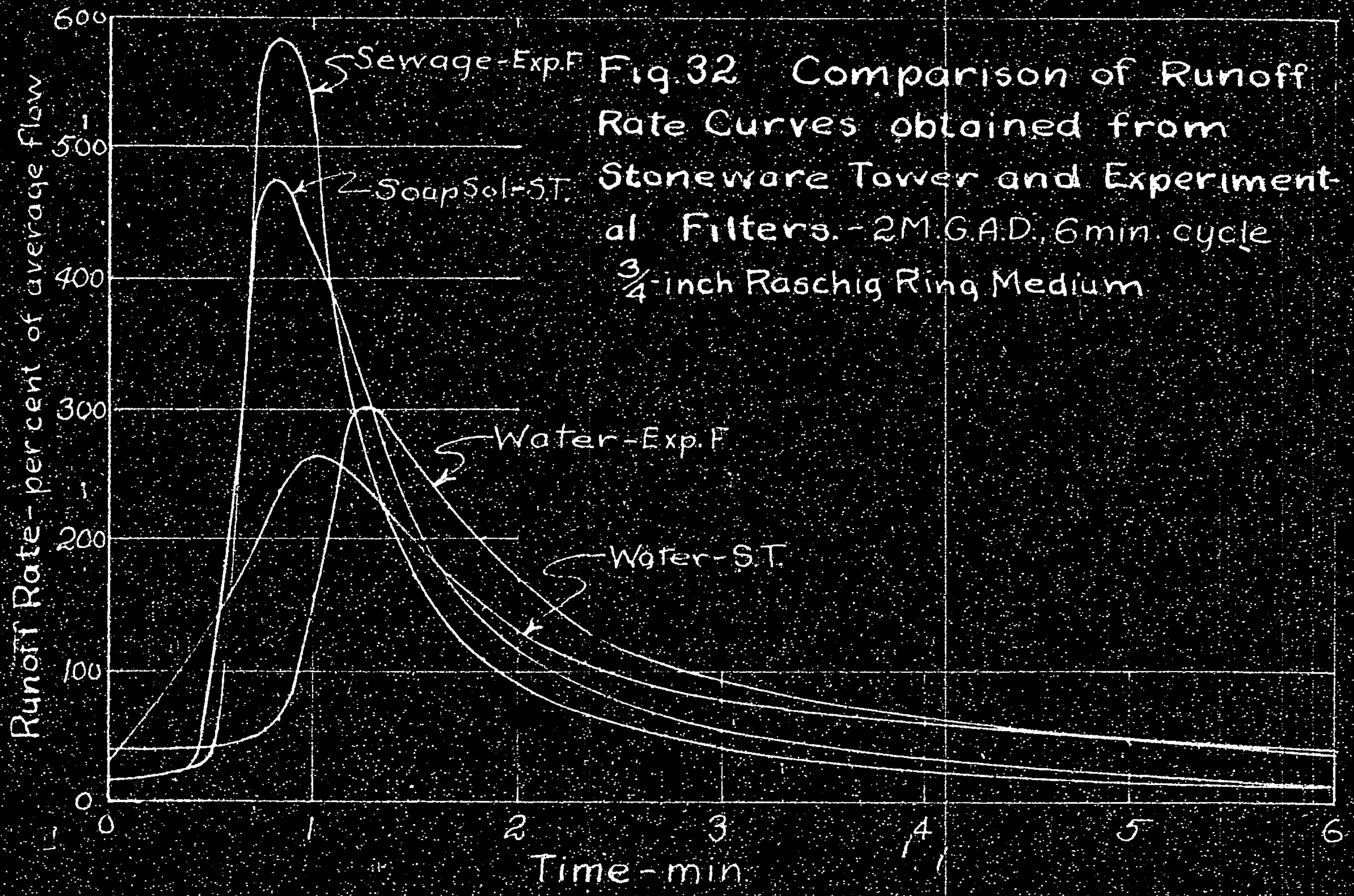


Fig. 32 Comparison of Runoff Rate Curves obtained from Stoneware Tower and Experimental Filters.-2M.G.A.D., 6 min. cycle 3/4-inch Raschig Ring Medium

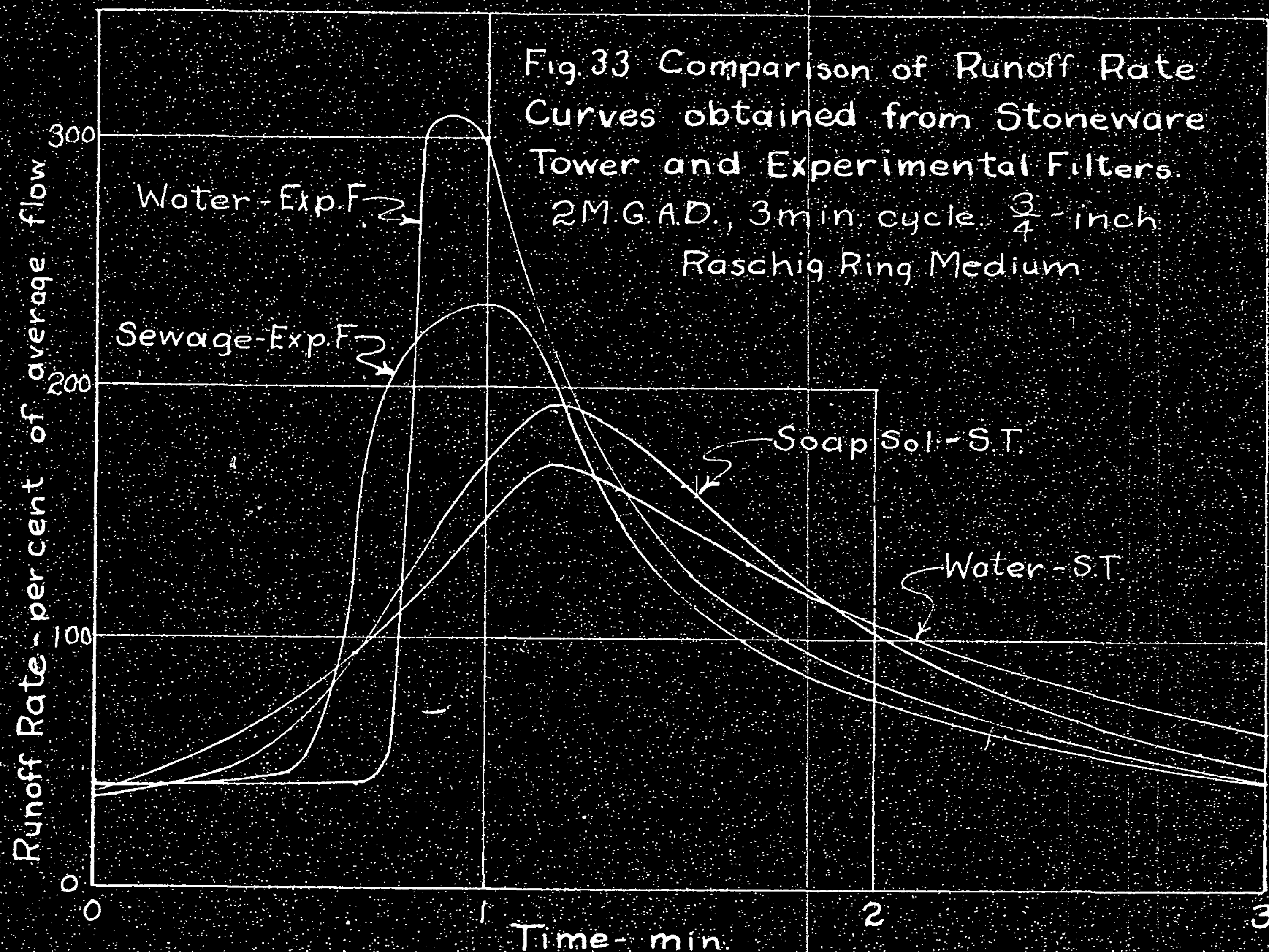


Fig. 33 Comparison of Runoff Rate Curves obtained from Stoneware Tower and Experimental Filters. 2 M.G.A.D., 3 min. cycle. $\frac{3}{4}$-inch Raschig Ring Medium

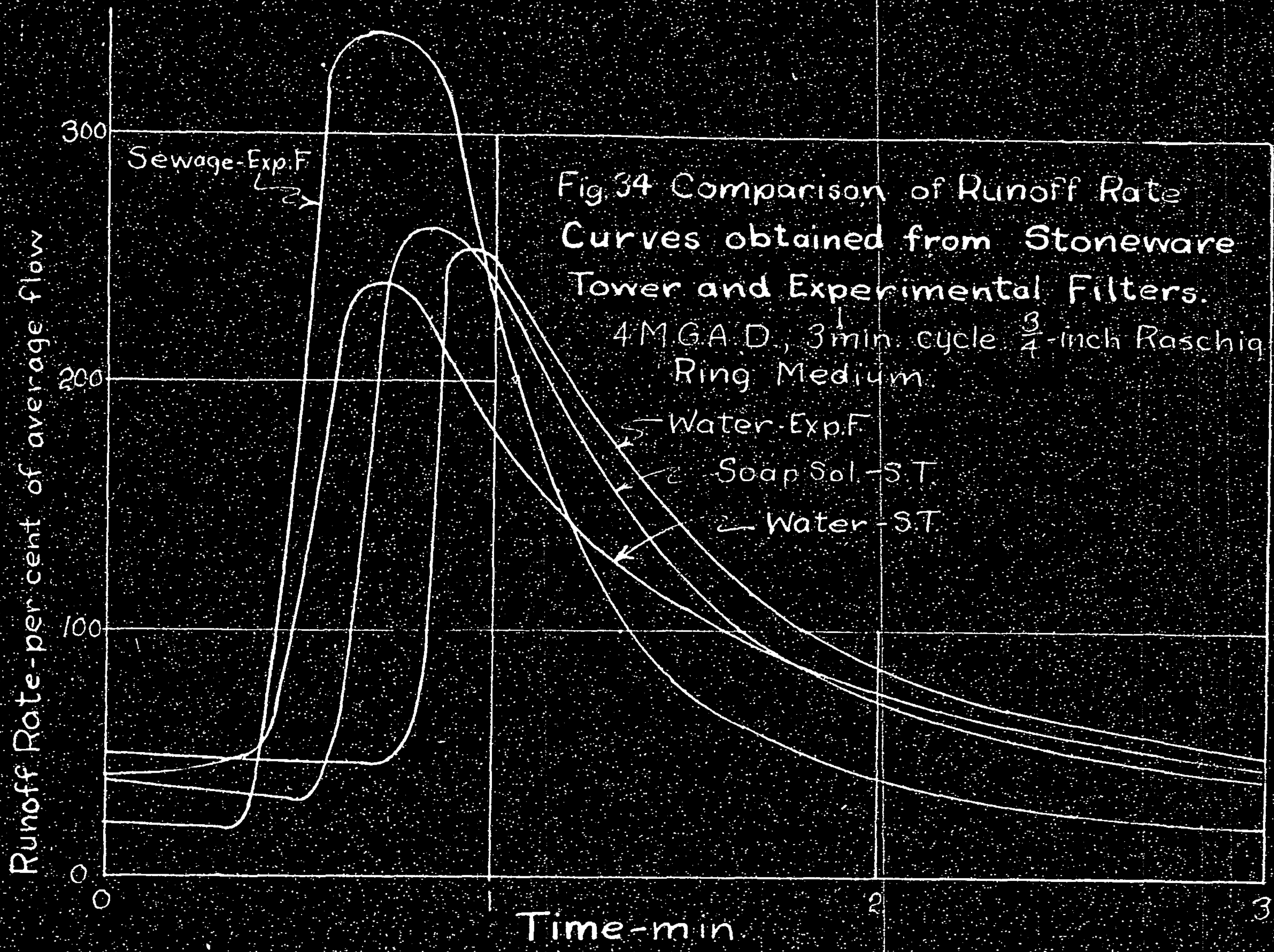


Fig.34 Comparison of Runoff Rate Curves obtained from Stoneware Tower and Experimental Filters.
4 M.G.A.D., 3 min. cycle. $\frac{3}{4}$-inch Raschig Ring Medium.

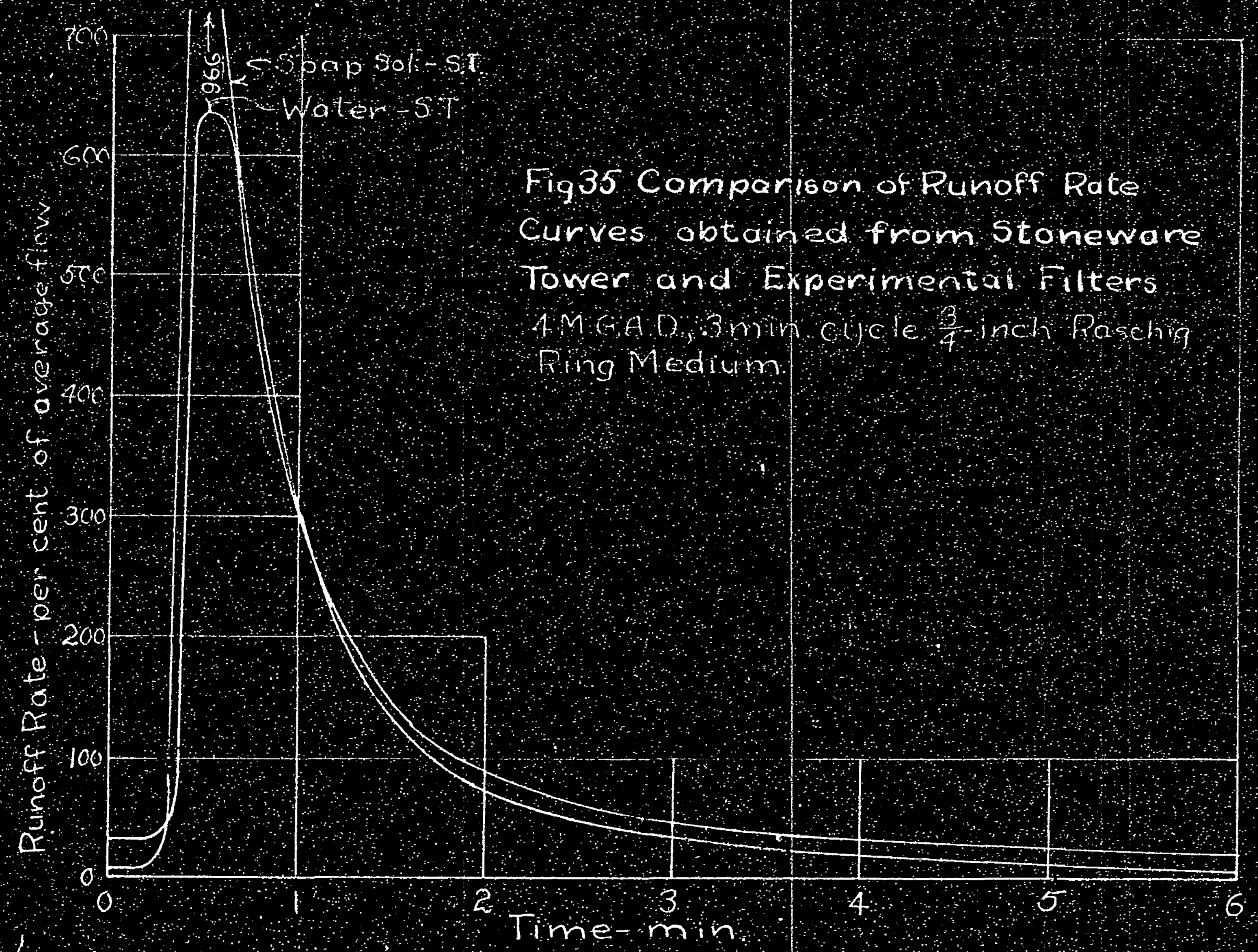


Fig 35 Comparison of Runoff Rate Curves obtained from Stoneware Tower and Experimental Filters
4 M.G.A.D., 3 min. cycle. $\frac{3}{4}$-inch Raschig Ring Medium.

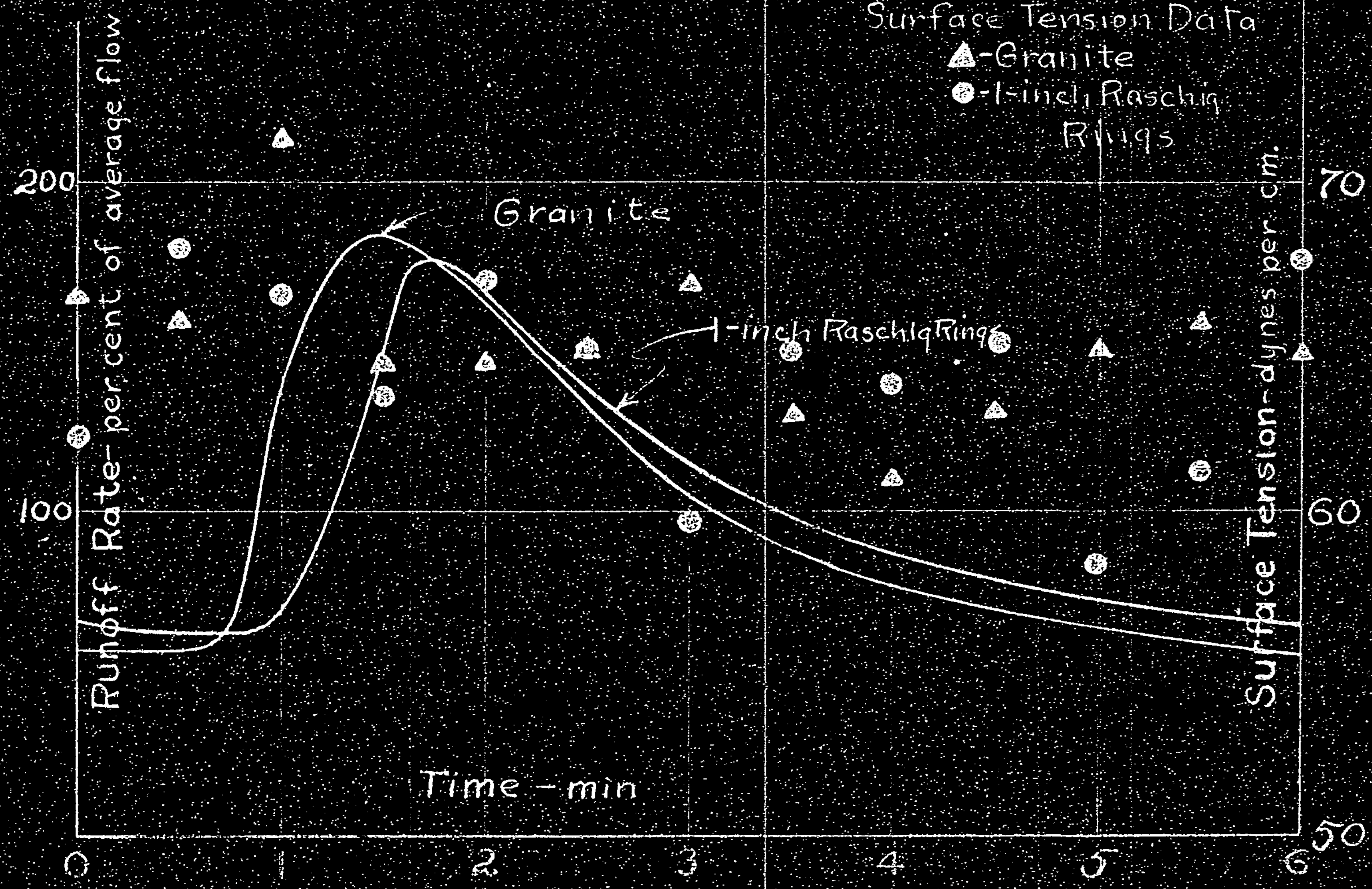
or whether another factor is responsible.

It was found that the surface tension of the effluents from the filters which were the most nearly purified, were very near that of water. This suggested the idea that perhaps surface tension determinations could be used as a criterion of purification. In general it can be said that stable materials in solution in the effluents are either surface tension increasing compounds or have no effect on surface tension. On the other hand, the unstable organic compounds which are found in sewage are surface tension lowering compounds. Thus as the unstable organic compounds are removed in the process of purification the surface tension of the liquid should increase, approaching that of pure water.

An investigation was made to determine if a relationship existed between the surface tension of the filter effluents and the rate of runoff. That is, surface tension determinations were made of the filter effluents every thirty seconds for several cycles in an attempt to determine if there is any correlation existing between the variation in surface tension and the point of maximum runoff rate. The data obtained in this manner are shown in Fig. 36 for both the granite and the one-inch Raschig ring filters. The corresponding runoff rate curves are shown for comparison.

Observation of Fig. 36 shows that the variance between individual surface tension determinations is so great as to prevent any conclusions being drawn concerning the relationship between the point of maximum runoff rate and variations in surface tension of the effluent.

Fig. 36 Relationship between Surface Tension of Filter Effluents and Time of application of Dose.
The Runoff Rate Curves are shown for reference.



D. Observations of the Biology of the Filters.

No attempt was made in this investigation to study the biology of trickling filters in any detail. The observations to be reported here are merely the casual observations resulting from the daily inspection of the filters and collection of the sample s for a period of nearly a year. Most of the observations are concerned with the larger living forms found in the effluents from the filters.

After the filters were placed in operation the first macroscopic form of life found in the effluents were species of small worms or nematodes. These appeared in the effluent of the one-inch Raschig ring filter about a week after the filters were first placed in operation. They appeared a day or two later in the effluent from the 3/4-inch ring filter and then successively in the 1-1/2-inch ring filter, the granite, Straight's block, and the 2-1/4-inch ring filters. These forms appeared at about the time the filters first operated normally, or after the film had developed. They did not appear in the effluent from the corn cob filter until months later and then only occasionally. They were very numerous in effluents from the smaller ring filters.

A few weeks later numerous Paramecia appeared in the 3/4-inch ring filter effluent and then successively in the other effluents, except that from the corn cobs where they appeared months later. Upon the appearance of the Paramecia the number of nematodes decreased. The effluents from the smaller rings at times contained great numbers of Paramecia. In a few weeks several Didinia were noticed in the effluents. The next day neither Parmecia nor Didinia were present. Instead, there were numerous Cyclops present. The Cyclops in turn almost disappeared, in a few weeks to again start the cycle over as before, nematodes, Paramecia, and a few Didinia, and then again Cyclops. The action seemed to be cyclic, with wave after wave of the various forms. Occasionally the Didinium would not be found at the end of the Paramecium stage.

After the filters had been in operation a month or thereabouts there were always occasional Psycoda larvae and some of the single celled stalked protozoan forms, Opercularia, although in varying numbers.

During the spring sloughing period unusually great numbers of Psycoda larvae with the protozoa attached were present in the filter effluents. Immediately after the sloughing became normal, the number of Opercularia and of larvae became less.

At one time a few snails were found in the effluents.

The effluent from the corn cob filter was at all times quite distinctly different than that from any of the other filters. During most of the winter the corn cob filter effluent contained very large numbers of Paramecia. This is of interest in view of the fact that the effluent contained little or no dissolved oxygen and no nitrates. The Paramecia apparently were not active nitrifiers in this case.

At times great numbers of extremely large vibro or spiral forms of life were found in the corn cob effluent. These were of such size as to be visible under a 30-power dissecting microscope. No attempt was made to culture these forms. Upon examination several spiral forms were found in the raw sewage, but they were neither as large nor as numerous as in the corn cob filter effluent.

During the fall and early winter the Psycoda flies were present in such numbers in the building as to be a nuisance. They were controlled by means of a pyrethrium spray. During the cold weather, a gas heating stove was installed to heat the building. It was found that when the room temperature was maintained above 95 degrees F. the flies seemed to disappear. As to whether the high temperature or the lowered relative humidity caused the flies to leave is not known. Although the temperature of the room was maintained high, the flies were still present in the filters, and great numbers of the larvae were to be found in the film.

Although not verified by identification there appeared to be two species of Psycoda present at the city plant. A microscopic examination of the microbial film during the early spring, after the spring sloughing period, showed it to be made of masses of the stalked protozoa, Opercularia and some species of what were thought to be water mold, attached to the rock, with the remainder of the life using these two forms as a haven of shelter.

At the time the spring sloughing period occurred in the city trickling filters, the experimental filter plant had been operating uniformly and normally with a room temperature above 90 degrees for several weeks. About a day later the experimental plant began to slough extremely heavily, although there were no observed changes in the temperature of the sewage or of the experimental plant, the rate of application or any other observable characteristic. It was observed that the sloughing period occurred at the time the frost came out of the ground. It may be speculated that the spring sloughing period is caused by some organism or enzyme perhaps present in the soil, which is released by the spring thaw, but which is not otherwise normally present in the sewage.

E. Notes on Probable Cost of Ceramic Filter Media.

The cost of ceramic filter media can not be readily determined by means of laboratory equipment. The methods of manufacture such as used for the production of the five cubic yards of media used in this experimental work would not be followed in a commercial enterprise. The methods used for the production of the experimental media were determined by the equipment available and expediency, rather than on the basis of greatest efficiency and lowest production cost. For example:

the media were burned in a kiln, commonly used for fine pottery. Commercially, an entirely different type of kiln would be used. Further the rings were all cut by hand as the column issued from the die. Obviously an automatic cutter would be used commercially.

The determination of the probable cost of ceramic media on a commercial basis is largely speculation. There are several factors that are almost beyond estimate. Further the unit costs for even standard shapes such as brick vary considerably from plant to plant. With this in mind an estimate based on a comparison with average unit costs for brick will be presented. The cost will be estimated for the production of one-inch Raschig rings. The cost of producing other sizes will be very nearly the same, although the unit costs will be distbibuted somewhat differently.

The estimated cost data are based on the following: The weight of the finished rings will average 45 pounds per cubic foot or 1200 pounds per cubic yard; the experimental one-inch rings average about 49 pounds per cubic foot, but the wall thickness was somewhat greater than necessary. For comparison; the weight of the 3/4-inch rings was 46.9 pounds per cubic foot and the 1-1/2 inch rings, 40.8 pounds per cubic foot.

When clay is burned there is considerable shrinkage in weight. For this estimate it will be assumed that 2500 pounds of raw material is necessary per ton of finished product. Iowa coal at $3.00 per ton is to be used for fuel in burning and drying. The drying operation will be considered as part of the burning operation, since the flue gases will probably be used for that purpose. The data presented for the cost of brick are taken from the Ceramic Products Cyclopedia (9). No manufacturing profit has been included in this estimate.

Estimated cost of producing one-inch Raschig rings under competitive conditions:

Item	Cost, per ton as mined	Cost, per ton finished product	Cost of Brick (for comparison)
Clay or Shale			
Royalty on land	$ 0.05		
Labor	.08		
Power	.02		
Pit Equipment	.05		
Explosives	.02		
Stripping	.03		
Haulage to plant	.07		
	$ 0.32	$ 0.40	
Plant Costs			
Grinding and pugging		0.30	$ 0.16
Screening		.18	-.--
Machine room labor		.45	.17
Equipment and repairs		.40	.10
Column oil and supplies		.20	.05
Incidentals		.50	
Plant Costs		$ 2.03	$ 0.48
Burning Costs			
Fuel, 500 lb. per ton		$ 0.75	
Labor		.12	
Investment cost		.30	
Supplies and repairs		.15	
Burning Costs		$ 1.32	
Storage and Loading Costs		$ 0.25	
Total Production Cost		$ 4.00 per ton	
		$ 2.40 per cubic yard	

Several of the items in the estimate should be explained. Of all the items entering into ceramic products the cost of the clay or shale is apt to vary considerably from plant to plant. The conditions at the clay pit are apt to vary so greatly, that only a typical cost sheet can be presented. The distribution among the various items is apt to be very different in any actual plant. In fact under some conditions some of the items may be omitted.

In this estimate rather generous additions were made in the plant costs over that of brick. The production of Raschig rings of the smaller sizes will require somewhat better preparation of the clay than is necessary for brick. Because of this a grinding and pugging cost of 30 cents per ton is allowed as compared with 16 cents per ton for brick. The clay need not be screened for the production of brick. For the production of small Raschig rings, 18 cents per ton has been allowed for screening. The small size of openings in the ring dies necessitates the clay be free from pebbles. A wet sedimentation process may be substituted to prepare the clay, but that has not been considered in this cost estimate. Machine room labor cost has been nearly tripled in order to allow for the greater care necessary for the forming and cutting operation. It is probable that the production of Raschig rings will be most economically carried on with small sized auger machines. It will probably be necessary to use considerable quantities of column oil or some patent type of cutter to properly cut the rings. 20 cents per ton is allotted for that purpose. In order to be sure that the estimate is conservative an emergency, or "incidentals", cost of 50 cents per ton has been allowed.

The burning costs for Raschig rings should be less than that for brick. In the first place, the wall thickness of the rings is so small as to make possible an extremely short firing period. In the second place, the draft loss through a bed of rings is so low as to permit firing through a dumped bed of the rings. It is not necessary to place the rings in sagers or other specially constructed containers while burning. It is quite possible that a scove kiln of the cheapest type would serve very well for the burning of the rings. Of course if a large amount of the rings is to be built by one plant it would probably be economical to use a continuous tunnel kiln or something of the sort. In a set-up of this sort an extremely short cycle would be possible. It may be possible to operate such a kiln on a 24-hour cycle. This would lead to an extremely high capacity for the size of the kiln. While the experimental Raschig rings were being made, it was found that the drying of the rings presented no problem. Even when drying at room temperature, a slight circulation of air served to dry the rings in a few hours.

The commercial manufacture of Raschig rings should be undertaken by a comparatively small plant. The capacity of the plant should probably be such as to necessitate its operating a considerable period, probably 24 hours per day, in order to supply the filter media required for any one city plant. This would necessitate some storage capacity. The smaller sizes of rings can be readily transported by means of conveying equipment such as used for sand or for small grain. Storage can be accomplished by merely dumping the rings in a pile on the ground much in the same manner as coal, sand and rock are now stored. Another conveyor can then transport the rings from the storage pile to the "coal" car in which they are to be shipped to the customer.

For the purpose of arriving at a cost estimate for the production of Raschig rings, the opinions of some of the manufacturers of ceramic products may be quite valuable.

Mr. S. I. Zook, former superintendent of the Des Moines Fire Clay Company, and now superintendent of the Fire and Pressed Brick Company of Dickenson, North Dakota, says that one-inch Raschig rings can be produced for $4.00 per yard and that under competitive conditions the price would be considerably below this.

Mr. O. J. Whittamore of the Sheffield Brick and Tile Company says that his organization would be glad to make one-inch Raschig rings for $5.00 per cubic yard.

Mr. L. L. Ladd of the Ladd-Cronin Engineering Company, manufacturers of circular continuous kilns, states that in his opinion the manufacture of Raschig rings for $5.00 per cubic yard should be a profitable undertaking.

Granite, which is the competitive material for trickling filter media has under normal conditions cost about $5.00 per cubic yard in place in the filter. The cost figures presented for Raschig rings indicate that the cost of the rings will probably be somewhere between $3.50 and $5.00 per yard at the manufacturing plant. If several dollars are added to this for shipping cost and for placing, it becomes evident that the Raschig rings can compete successfully with granite only when a higher rate of treatment is obtained, or some other equally valuable result achieved.

The exact ratio of the rates of treatment on the two materials for equal cost is difficult to obtain, but it appears from the estimate presented that if the Raschig rings are able to treat a waste at a rate of 25 to 50 per cent greater than granite for the same degree of purification, then Raschig rings give promise of achieving a strong competitive position.

F. Discussion of Results.

1. B.O.D. Reduction.

There was significant variation in the biochemical oxygen demand of the effluents from the filters during the first operating period, both in the shaken and settled samples. The 3/4-inch rings produced effluents containing the least B.O.D.; 12 and 35.4 p.p.m. for the settled and shaken samples respectively. The 1-inch rings produced somewhat more B.O.D.; 16.8 and 45.6 p.p.m., and the granite and 1 1/2-inch rings about equal amounts, 24 to 24.9 and 55.5 to 59.7 p.p.m. For some unexplained reason the 2 1/4-inch rings produced less B.O.D. in the settled sample than either the 1 1/2-inch rings or granite. The B.O.D. of the shaken sample, however, was greater than that from the granite or the 1 1/2-inch rings. The effluent from Straight's block was comparable with that from granite.

Similarly in the second operating period the 3/4-inch filter produced effluents containing the least B.O.D.; 34.3 and 66.3 p.p.m. for the settled and shaken samples respectively, as compared with 53.2 and 129.9 p.p.m. for similar samples from the granite filter. The effluents from the other sizes of rings contained successively greater amounts of B.O.D.

During the third operating period there was only a slight difference in the B.O.D. of the samples. The slight difference that existed during this period was in the reverse order from that obtained during the first two periods; the largest rings produced the least B.O.D.

The B.O.D.$_s$ of the settled samples were less during the third operating period than during the second, although the dosage was 8 M.G.A.D. during the third period and only one-half of that, or 4 M.G.A.D. during the second period. The dosing cycle was 3 minutes during both periods. There was somewhat greater irregularity in operation and greater fluctuations in room temperature during the second period than in the third. The average temperature of the sewage during the two periods was 52 and 56 degrees F. respectively.

The average B.O.D. of the influent was substantially the same throughout the three operating periods. This does not, however, imply that the B.O.D. remained constant during the experiment. On the contrary the B.O.D. of the influent varied widely from morning to night flow and from day to day. During periods of high water or heavy rains the B.O.D. of the influent dropped to extremely low values due to infiltration of water into the sewers.

It is quite obvious that the amount of B.O.D., in pounds, removed in any given filter was very much increased as the rate of application was increased. For example, in the case of the granite filter at the 2 M.G.A.D. rate the reduction in B.O.D. for the settled sample was 170 p.p.m. or about 2800 pounds per acre per day. At the 4 M.G.A.D. rate the B.O.D. reduction was 130 p.p.m. or about 4300 pounds per acre per day. At the 8 M.G.A.D.

rate the B.O.D. reduction was 142 p.p.m. or about 9500 pounds per acre per day. Similarly for the shaken samples the reductions were 2200, 1800, and 6800 pounds per acre per day for 2, 4, and 8 M.G.A.D. rates, respectively. The increase in B.O.D. removal with increasing rates of application was similar in the other filters.

The fact that these experimental filters were operated successfully at the rate of 8 M.G.A.D. without any apparent clogging leads to the conclusion that present day filters are underdosed. (These filters are being operated at present at the rate of 16 M.G.A.D.) The rate of application necessary for the maximum B.O.D. removal, in terms of pounds of B.O.D. per acre per day, is not definite from this investigation, but it is evidently above 8 M.G.A.D.

In this investigation sewage of a concentration of 190 p.p.m. of B.O.D. was satisfactorily treated by trickling filters at the rate of 8 M.G.A.D. with a 3 minute dosing cycle. Furthermore, a milk waste of over 1000 p.p.m. B.O.D. was satisfactorily treated at the rate of 2 M.G.A.D., with a 6 minute cycle. In no case did clogging make the filter inoperative. In view of the fact that commercial filters have been known to clog and pond badly when treating domestic sewage at the rate of 2 M.G.A.D. and milk waste at a much lower rate, an explanation is necessary. Several possible explanations come to mind: First, the presence of quantities of inert suspended solids in the waste may cause clogging. Second, a somewhat shorter dosing cycle was used in the experimental plant than is used in practice. Third, the filter media in the experimental filters were supported on wood grid of such open structure as to offer little or no resistance to natural ventilation. It is probable that considerably more than normal natural ventilation occurred.

If the short dosing cycle allowed the higher rate of waste application without clogging, then a still shorter cycle or continuous dosage should allow even higher rates of application. Further work is needed to substantiate this.

If on the other hand, the greater amount of natural ventilation obtained in the experimental filters allowed the higher rate of waste application, then the use of artificial ventilation should allow the use of even higher rates of waste application. The work of Levine on the treatment of packing house wastes by an artificially aerated filter seems to support this idea.

The relationship between surface of the filter media and the B.O.D. removal is shown on Fig. 37 (settled sample) and Fig. 38 (shaken sample). The data presented on these figures indicate that during the first two operating periods there was a relationship between the B.O.D. removal and the surface of the medium. In the third period, however, this relationship no longer existed. Instead of obtaining a greater removal of B.O.D.

on the medium having the larger surface there was little if any difference in the effluents from the various media. In fact, the greatest B.O.D. removal occurred on the medium having the smallest surface.

The notation "2 1/4, S, G," etc. on the bottom of Fig. 37 and 38 refers to the various media: 2 1/4-inch rings, Straight's block, granite, etc.

The hypothesis is advanced that at the higher rate of waste application, the surface of the medium is no longer the limiting factor, but that the amount of air which may reach the active filter medium becomes the limiting factor. Considering the fact that the smaller media will have a greater resistance to air flow, it is only natural that a smaller amount of natural ventilation would occur. If the amount of natural ventilation is the limiting factor in the filter operation, then the filter media having the largest interstice size should be expected to give the greatest B.O.D. removal, other things being equal. In this case the 2 1/2-inch rings which have the largest interstice size showed the greatest B.O.D. removal.

The theory that trickling filters operate as effective colloiders has been advanced in the past. Further evidence of this action is presented in Table No. 18, in the amount of B.O.D. removal as a result of settling. In every case a very appreciable amount of the B.O.D. removal credited to the filter was really a colloider action, where the material was changed

Fig.37 Curves showing the relationship between the B.O.D. of the effluents and the surface of the medium. Average influent concentration - 190 p.p.m.

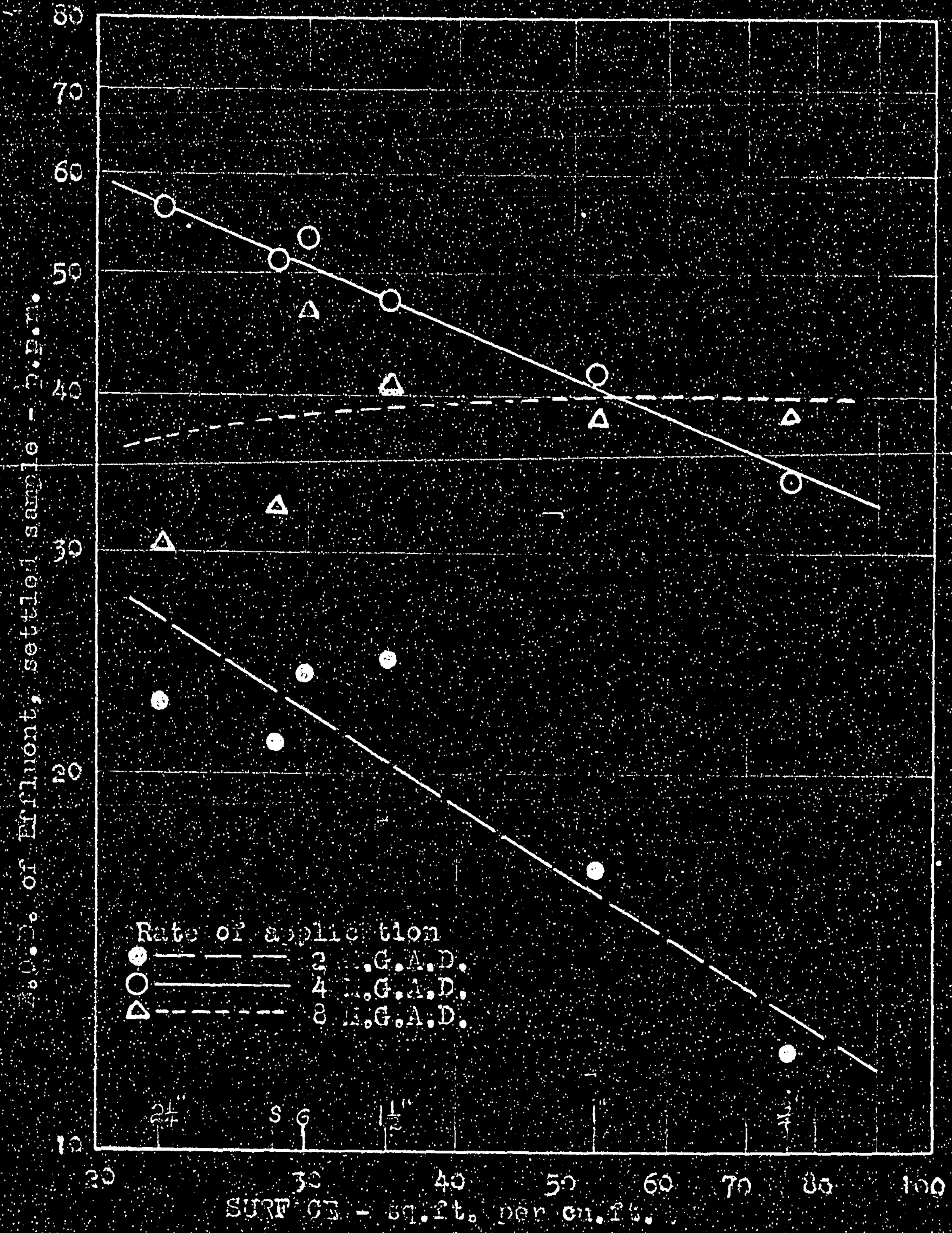
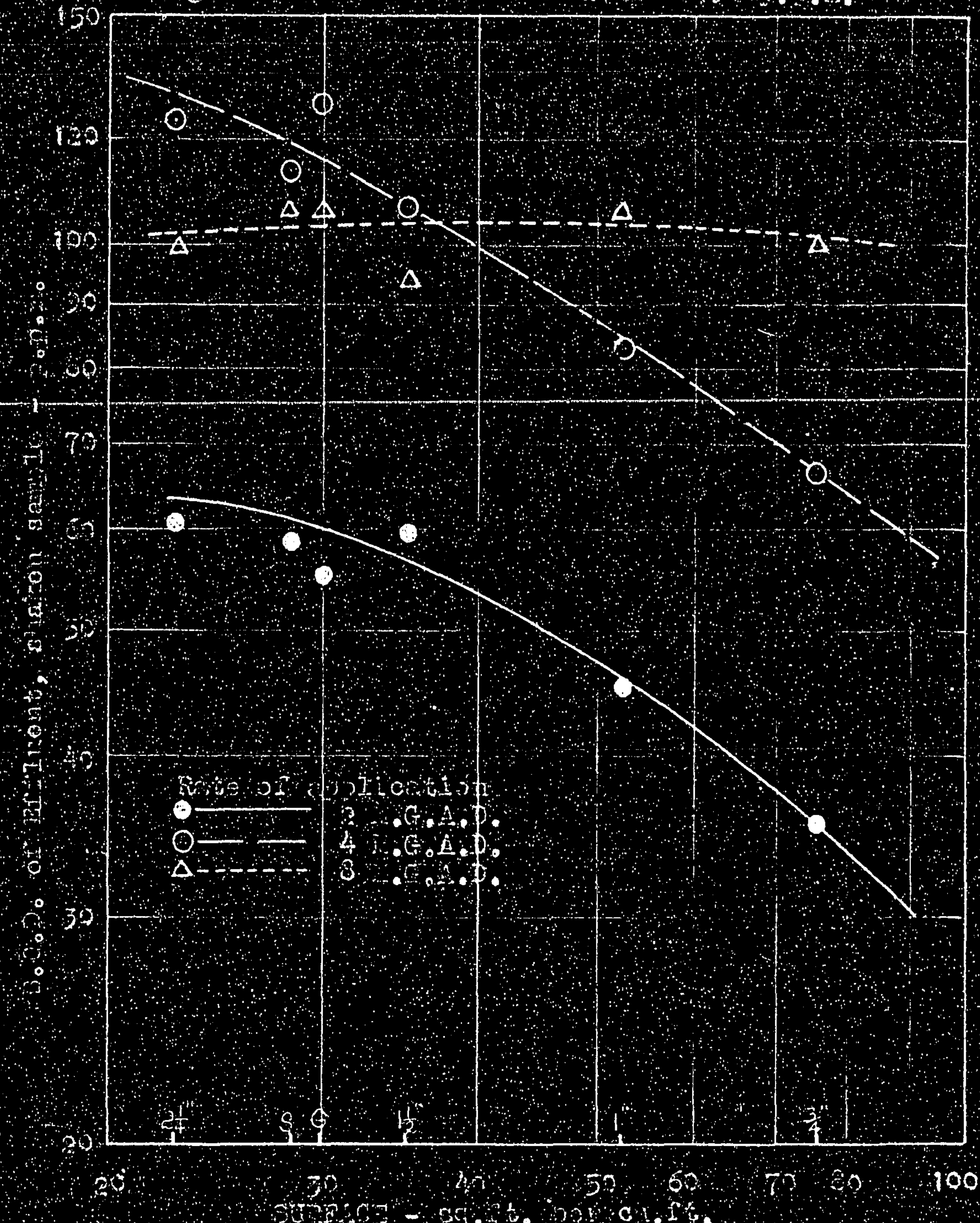


Fig.38 Curves showing the relationship between the B.O.D. of the effluents and the surface of the medium. Average concentration of influent - 190 p.p.m.



into a form readily removed by settling. In nearly every case over 50 per cent of the B.O.D. content of the shaken effluent sample could be removed by settling.

2. Relative Stabilities of Effluents.

The relative stabilities of the filter effluents are of great interest. During the first operating period there was no substantial difference between filters, all the effluents being very stable. In the second and third operating periods, however, the smaller ring filters produced effluents with distinctly greater relative stability. There is insufficient explanation for the increased stability during the third period as compared with the second period.

3. Dissolved Oxygen Content of Effluents.

The dissolved oxygen content of the various effluents, reflect the relative stabilities of the effluents. During the first operating period all of the effluents contained substantial amounts of dissolved oxygen. During the last two operating periods the smaller ring filters produced effluents containing distinctly greater amounts of dissolved oxygen.

4. Nitrification.

The nitrogen determinations further substantiate the relative stability determinations.

The nitrification obtained in the 3/4-inch ring filter is unusually great. The relationship between the nitrification obtained in a filter and the surface of the filter medium are graphically shown in Fig. 39 and 40. Inspection of the data in these figures indicates that the nitrification was a function of the surface area of the medium. It should be noted that as the nitrification obtained increased there was a simultaneous decrease in free ammonia and organic nitrogen.

5. Solids.

Inspection of the settlable solids data yields the information that the volume of the settlable solids is less in effluents from the filters containing the smaller sizes of rings than from granite or the larger sizes of rings. The volume of settlable solids in the 3/4-inch filter effluent was only slightly over 50 per cent as great as in the granite filter effluent. The significance of this fact requires further investigation.

6. Ventilation.

Early workers have shown that the nitrification in a filter may proceed even though the oxygen content of the filter atmosphere was as low as 1 to 3 per cent. Levine and others hav shown that when ventilation in a trickling filter is impeded the B.O.D. removal is decreased very markedly. There is evidence presented in this investigation to show that these two statements are quite in accord with each other. During the third operating period the B.O.D. removal was markedly decreased, the greatest B.O.D. removal occurring on the filter having the smallest surface. During this period, however,

Fig. 39 Curves showing relationship between surface of filter medium and nitrates produced

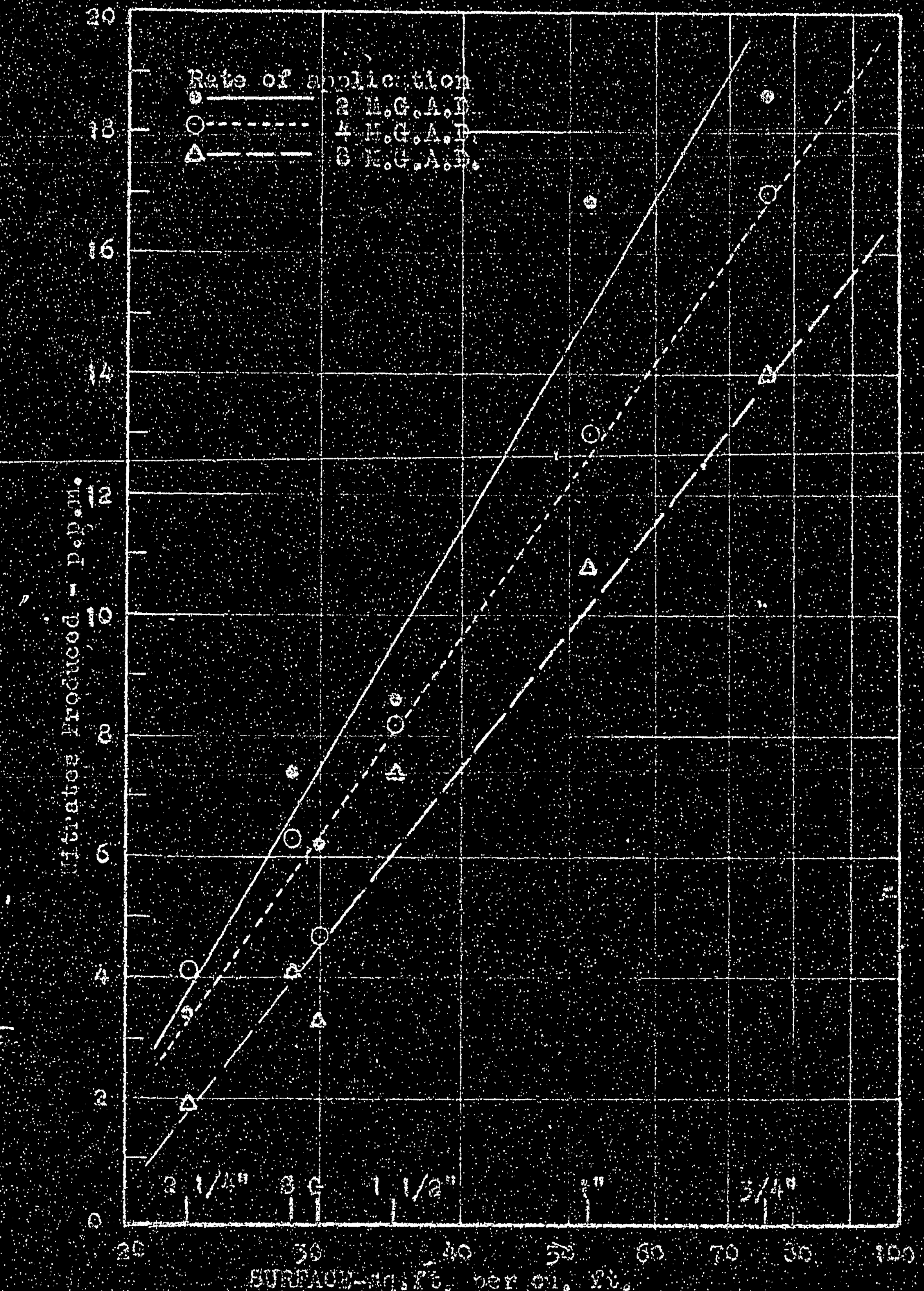
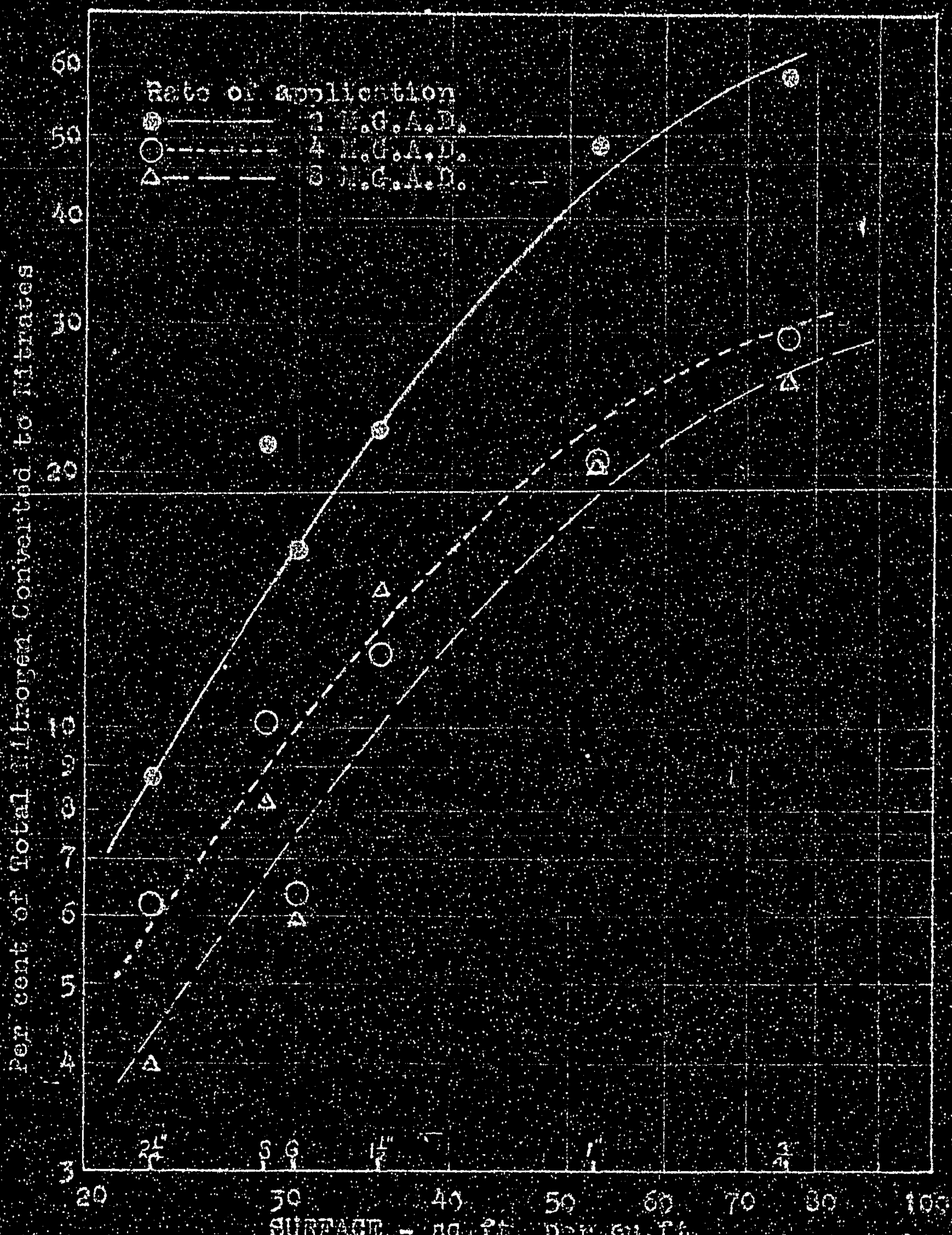


Fig. 40 Curves showing relationship between surface of filter medium and nitrates produced



there was no similar decrease in the nitrification. Each has suggested that the B.O.D. removal is limited by comparatively low concentrations of carbon dioxide. If this is true, then it is possible that during the third period insufficient ventilation occurred to keep the carbon dioxide concentration below this limiting factor, yet was sufficient to maintain the oxygen content considerably above the limiting value for nitrification. These speculations need be studied further.

F. Discussion of Results.

7. A Trickling Filter as an Absorption System.

A trickling filter will be considered as a very complex absorption system. A diagram of a portion of such a system is shown in Fig. 41. The essential parts of the system are: The filter medium (shown as a portion of a Raschig ring in the diagram); the biological or microbial film; the waste being treated, flowing as a thin film over the microbial film; the air passage and the interfaces between the components. (The diagram includes only the system present on the outer surface of the Raschig ring. A similar system exists on the inner surface.) With the possible exception of the filter medium, all the components of the filter are subject to variations, both physical and chemical. Many of the variations are very complex in their nature because of their interdependance. Many of the reactions that occur in the filter are not understood. Some speculations concerning the typical reactions, limiting factors and obtaining conditions will be discussed here.

Before the operation of the filter is considered it may be well to discuss something of the nature of sewage, the waste being applied to the filter. Sewage is water polluted by organic substances of varying stability and varying degrees of dispersion. These organic substances are principally carbohydrates, with smaller amounts of proteins

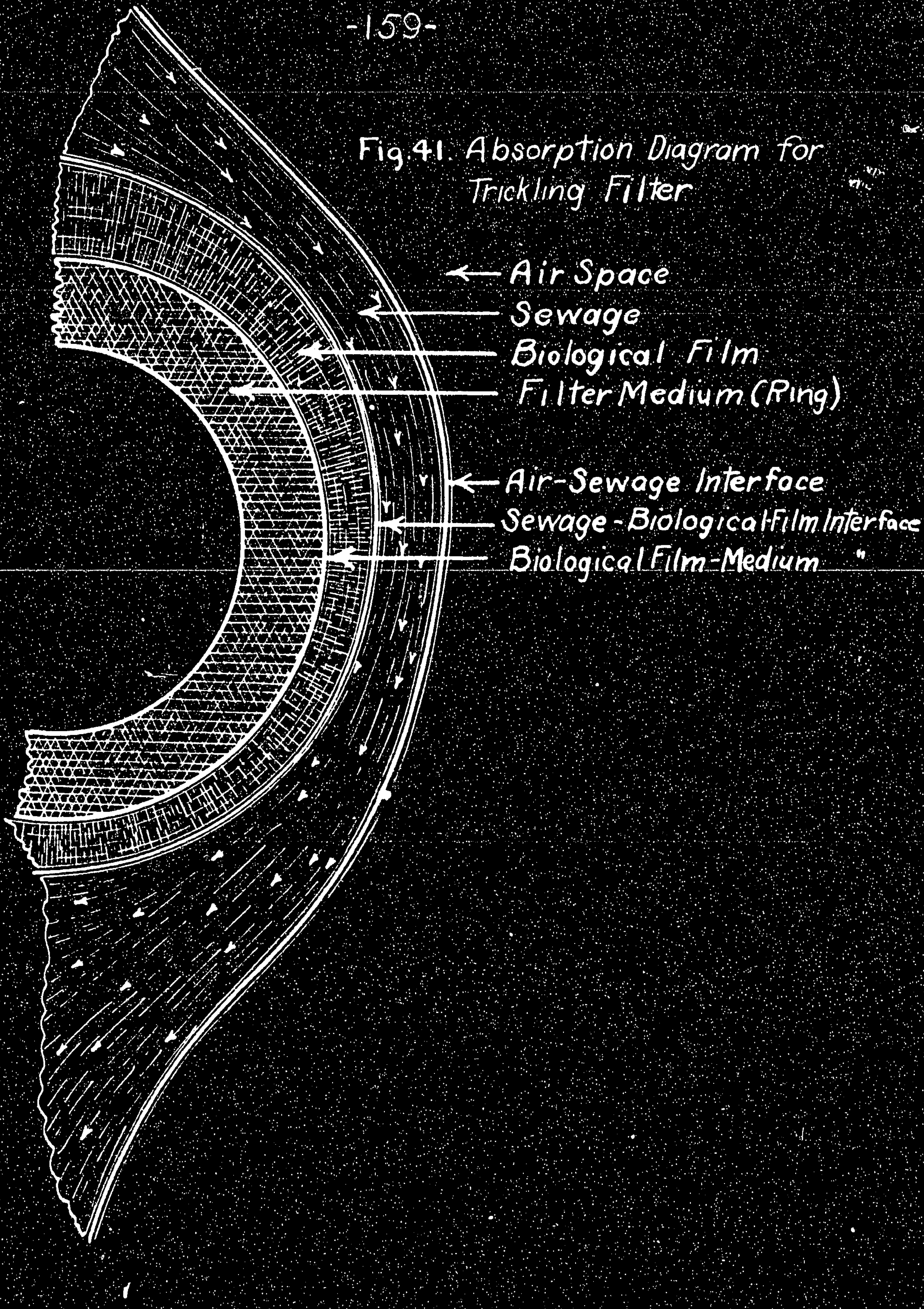


Fig. 41. Absorption Diagram for Trickling Filter

and fats. These organic materials may be in solution, in colloidal dispersion, or as suspended solids. The larger particles of suspended solids are usually removed before the sewage is applied to the filter. These organic materials may be in their original form or they may have been changed since entering the sewage. Many of the less stable compounds have already undergone considerable change before being applied to the filter. If considerable change has occurred in the sewage before entering the sewage treatment plant the sewage may become septic, and foul smelling.

The sewage also contains inorganic dissolved solids, and perhaps some colloidal solids not unlike the ground water found at the origin of the sewage. In most cities the sewage contains considerable ground water which seeps into the sewer system. Furthermore, it must be remembered that sewage is largely the waste of a community being carried away by a flow of water. The water which is acting as a carrier usually has a local origin. The ratio of inorganic to organic solids varies greatly. The inorganic solids may be considerably more than half of the total solids. The total solid content of the sewage is seldom over 0.1 per cent. That is, the water in sewage constitutes over 99.9 per cent of the total, making sewage a dilute solution indeed. It is this dilute characteristic of sewage that has hampered all attempts at recovering something of value from the sewage.

In addition to the solids contained in sewage, dissolved and loosely combined gases are present. The gases commonly present are nitrogen, oxygen, carbon dioxide, hydrogen sulphide, and to a smaller extent other gases.

Another normal constituent of sewage, which is very small in volume, but of very great significance is the microscopic life. Numerous species of microscopic life are represented in a greater or lesser degree. Popular opinion considers the biological life largely from the pathogenic viewpoint; that is, from the viewpoint of the possible diseases that the biological life may cause. It should be pointed out that the pathogenic forms that are present in sewage represent a very small percentage of the total living population. The organisms which are present in greatest numbers are those which are able to utilize the organic materials present in the sewage, and in so doing stabilize the waste. Pathogenic organisms are generally not very active under the conditions found in sewage. It is the biological life present in the sewage which provides the "seed" for the development of the biological or microbial film upon which the operation of a biological filter depends.

Sewage, a foul smelling liquid of complex, heterogenous composition is applied to the upper surface of a filter. The sewage flows, by gravity, through the filter in comparatively thin films. These films of sewage come in contact not with the filter medium but rather with the microbial film. As the sewage flows through the filter the process of purification goes on. To bring about this process a number of processes are simultaneously going on. A consideration of the action occurring at the interfaces is of interest. At the air-sewage interface oxygen is being absorbed, and carbon dioxide given off. If the sewage is septic some hydrogen sulphide may also be given off, but this is not the normal condition. The unstable organic materials in sewage are for the most part surface tension lowering materials. Gibbs (7) found that materials which lower surface tension tend to migrate toward the interface, and conversely that substances which increase the surface tension tend to migrate away from the interface. In sewage, the organic materials migrate toward the two interfaces; the air-sewage interface and the sewage-microbial-film interface. Surface tension lowering is largely brought about by an orientation of the surface tension lowering molecules or colloidal particles at the surface. In the case of the sewage this orientation may be sufficient to exert a masking effect, which very materially limits the rate of oxygen absorption and carbon dioxide liberation at the air-sewage interface.

At the sewage-microbial-film interface, however, the orientation of the organic materials is effective in bringing the organic materials in proximity with the biological life.

Here several actions probably take place. A large part of the organic colloidal material is probably coagulated and adsorbed for future digestion. The time interval necessary for the sewage to flow through the filter is too short to allow a complete digestion of the complex colloidal particles. Colloidal particles are coagulated at the microbial film surface, their digestion can then proceed for any necessary length of time. Coagulation effectively removes the putrescible material from the sewage, even though it does not destroy that material. At the same time simpler compounds, perhaps in solution, such as sugars, ammino acids, etc., are in a condition to be readily acted upon by extracellular, splitting enzymes, which are being given off by organisms in the microbial film. Most elementary forms of life are unable to utilize even comparatively simple sugars, without preliminary extracellular splitting. In general most cells give off extracellular enzymes which serve to prepare the available food for ingestion into the cell. Carbon dioxide, which is an end product of metabolism is being given off by the microbial film and must pass through the sewage-microbial-film interface. Part of this carbon dioxide is dissolved or loosely combined in the sewage. Some passes into the air at the sewage-air interface. The amount of carbon dioxide which is absorbed in the sewage is dependent on temperature, pH, salt concentration, total alkalinity, etc. The oxygen absorbed at the air-sewage interface is utilized variously. The larger portion passes through the sewage-microbial-film interface to supply the needs of metabolism. Some oxygen is used in direct oxidations not brought about by biological processes. Some oxygen is also used in the oxidation of inorganic compounds such as hydrogen sulphide and ferrous sulphate which may be present in the sewage. In the lower portion of the filter some of the oxygen is utilized in the nitrification process. In this case, however, it is probable that the oxygen must pass through the sewage-microbial-film interface and be absorbed by the nitrifying organism.

It is of interest to consider the possible distribution of surface tension lowering substances between the sewage-air and sewage-microbial-film interfaces. As the sewage is applied to the filter the tendency is probably towards an equal distribution, with the resulting masking of both interfaces. At the sewage-microbial-film interface, these substances are being coagulated or adsorbed quite rapidly. No similar reaction or removal of surface tension lowering substances occurrs at the air-sewage interface. As soon as the concentration of surface tension lowering substances at the sewage-microbial-film interface becomes materially lower than at the sewage-air interface, the surface tension lowering substances start migrating from the sewage-air interface to the sewage-microbial-film interface. Soon the sewage-air interface is no longer masked and the oxygen absorption and carbon dioxide liberation is no longer impeded. It is probable that if oxygen could be added to the sewage in some other manner than through the air-sewage interface, by adding water containing dissolved oxygen, for instance, the biological oxidation process in the filter could be initiated more rapidly. A highly oxygenated effluent might be returned and mixed with the influent in the pump well, for example.

The mic obial film is a heterogenous mass of biological life. Physically it is made up of masses of thread-like water mold and protozoa, in which innumerable other forms are enmeshed. The film is a heterogenous zoogloeal mass. The conditions in the film are assumed to be aerobic, thus precluding very active anaerobic growth, although some forms which are predominantly anaerobic are present at times. The larvae of filter flies are perhaps the largest species present. To enumerate the types commonly found is out of the question. Suffice it to say that water molds, numerous types of protozoa, algae, nematodes, and bacteria are present in great numbers. The physiology of these various forms is not sufficiently well known to suggest the function of each in the process of purification with any degree of certainty. It is probable that the motile forms of biological life in the microbial film migrate into the region of the sewage-microbial-film interface and act in digesting the coagulated material. Somo of the larger forms, such as the Psycoda larvae, in their migrations back and forth through the microbial film probably loosen the film somewhat, and allow it to be readily washed off the medium. This loosening and sloughing process prevents the film from becoming of such thickness as to clog.

At the same time some of the organic compounds formed by enzymatic splitting diffuse into the film to be ingested by the various forms of biological life. Proteins are, of course, first broken down into ammino acids, and these in turn into ammonia and organic acids. The ammonia is later converted into nitrates, in the process of nitrification. Some of the nitrates formed act as oxidizing agents and are again reduced to nitrites. It is thought that nitrites and ammonia or ammino acids react to liberate free introgen. Such an action would account for the loss of nitrogen in a filter. Considerable nitrogen loss may also be explained by the insects which leave the top of the filter.

Sewage may be applied to the filter bed variously. In the experimental work discussed in this paper, and in many plants the waste is applied periodically, that is, a dose is applied at intervals with a rest period between. The methods of flow of waste through the filter is discussed more in detail under "Runoff Studies". In general it can be said that the flow through the filter is determined by the rate of application, the dosing cycle, the temperature, surface tension and viscosity of waste, the nature of the filter medium and the condition of the biological film. If the waste is applied more or less continuously as it is in some of the more recently constructed plants the film of liquid flowing through the filter may be expected to remain somewhat uniform in thickness. In most filters however the waste is applied more or less periodically, the dosing cycle varying from a few seconds in some of the rotary type of distributors to 20 or more minutes when using a dosing tank and spray nozzles. The thickness of the film of waste may vary from zero thickness to the point where the entire interstice space of the medium is filled with sewage. Between these two conditions three or more types of flow are possible. When the interstial space is completely filled with waste the flow is defined as turbulent flow in a closed channel or duct. If the interstial space is small as in a sand filter the flow may become streamline flow in a closed channel. Either of these conditions is met with only rarely, and then only at extremely large doses or in a clogged filter. At somewhat less flow the conditions are first those of turbulent flow in an open channel. At low rates of flow a peculiar condition is encountered which may be spoken of as "capillary flow", similar to the flow through wick or other cloth, the flow in this case being through the interstices of the microbial film. In a well developed filter this capillary flow will continue for some hours after the waste application has ceased.

It should be pointed out that the flow conditions are not the same at the top of the filter as at the bottom or at any intermediate point. With a periodic application of waste at the upper surface of the filter it is apparent that the greatest variation in rate of flow through the filter will occur at the top of the filter with an ever decreasing variation in the rate of flow as the depth of the bed increases. That is, the flow through the bed is smoothed out as it progresses through the bed. A filter medium having an unusually heavy microbial film which offers considerable resistance to flow has a greater tendency toward smoothing out the flow than a medium with very large size interstices. It follows that for a given dosing cycle the more uniform the runoff from the filter the longer the period of contact in the filter bed, altho gh there are several factors which may offset this. Inasmuch as the microbial film at the top of the filter bed is usually the heaviest, with little film at the bottom of the bed, the greatest resistance to flow occurs at the top of the bed and it is probable that the average flow conditions in the bed more nearly approach those of the filter runoff than the rate of waste application.

The film varies from top to bottom of the bed as the nature of the process being carried on at a given point in the bed varies. That is, the process of breaking down a waste applied to the filter follows the line of least resistance.

The carbohydrates are on the whole the most unstable materials present in sewage. As a consequence the carbohydrate breakdown occurs first in the filter. It is this breakdown which supplies a great amount of energy for the metabolic processes of the microbial film. Because of the energy release of this breakdown and because the ease of the breakdown the microbial film at the top of the filter grows quite prolific and functions most actively. It should be pointed out that the "colloider" action of the filter occurs near the top of the filter. The digestion of the coagulated materials also must occur near the top of the filter. Almost simultaneously with the carbohydrate breakdown, though somewhat delayed is the breakdown of proteins in the waste. The proteins are very apt to be in an insoluble, for or at best in colloidal form. As a result the protein breakdown occurs lower in the filter, but not as rapidly as the carbohydrate breakdown. It is probable that the protein breakdown is brought about by a more specialized process than the carbohydrate breakdown. Proteins are possibly coagulated with other colloids. Then the process of digestion yields soluble ammino acids which pass down through the filter to be again broken down to ammonia and organic acids. This accounts for the preliminary increase in free ammonia in a filter. The breakdown of proteins to ammonia, water and carbon dioxide is followed by the process of nitrification. The energy release in the process of nitrification is much more meagre than in the carbohydrate breakdown. As a result the process does not become extremely active, to the point of approaching completion, but goes on rather slowly over a considerable depth of filter. If the filter is seriously overloaded, the first two processes mentioned consume such a large portion of the total depth of the filter as to prevent the nitrification process from becoming at all noticeable.

There are many factors that enter into determine the purification obtained in a given filter or to determine the maximum rate a given filter can be operated without clogging. Which factor becomes the limiting factor depends upon which factor is the "neck to the bottle" so to speak. Under some conditions one factor may be limiting under other conditions, another factor may become the limiting factor.

At the low rates of waste application used early in this investigation the nitrification and B.O.D. removal was apparently a function of the surface of the medium. At higher rates of waste application the amount of natural ventilation obtained probably became a limiting factor, in B.O.D. removal. It is probable that the presence of comparatively small amounts of carbon dioxide impedes the B.O.D. removal, but has less effect on the nitrification process. Early workers have shown that nitrification proceeds even though the oxygen content ofthe filter atmosphere is only 1 to 3 per cent.

In some filters the rate at which the coagulated colloids can be digested so as to prevent clogging, becomes the limiting factor. This digestion is, however, probably dependent upon the ventilation rate.

At the upper surface of the filter the rate of oxygen absorption by the sewage is probably a limiting factor, especially when the sewage is septic.

8. Suggestions for Future Work.

The suggestions for future work may be divided into two classes: fundamental and practical research.

The fundamental research should include studies on the physiology of the various forms of life found in trickling filters. This is especially necessary for some of the protozoa and some of the higher forms. Fundamental work should be carried on to determine the limiting concentrations of oxygen, carbon dioxide, etc., for B.O.D. reduction and nitrification. Perhaps the Barcroft technique on the Warburg respirimeter would be useful in this work.

The effect of surface tension on the rate of gas absorption at a sewage interface should be studied further.

From a practical viewpoint, the effect of artificial ventilation, continuous dosing, double filtration, (using a washable filter for the first filtration), depth of filter, surface of medium, and recirculation of effluent should be studied further. In the case of the practical research the effort should be, not to cover all possible conditions, but to arrive at the optimum conditions by the shortest path. Needless to say, the fundamental research should point the way for the practical.

IV. SUMMARY

In a preliminary investigation, two filters of 4 square feet in area and 6 feet in depth, one filled with 1 to 3-inch granite, the other with one-inch Raschig rings, were charged with a synthetic waste produced continuously from a mixture of dried sheep manure and spray dried skim milk powder. The B.O.D. concentration of the synthetic waste was increased from an average of 117 p.p.m. during the first period of operation from May 23 to June 20, 1933, to 567 p.p.m. during the second period from June 20 to August 25, 1933, and finally to 999 p.p.m. during the third period of operation from August 25 to September 28, 1933. The rate of application was 2 M.G.A.D. with a 6 minute dosing cycle. Distinctly better purification was obtained with the Raschig ring filter.

Although the concentration of the influent was as high as 1400 p.p.m. at times there was no clogging of the ring filter. The clogging that occurred on the granite filter cleared itself without any remedial measures being used or the filter taken out of operation.

Purification practically ceased when bottom ventilation was stopped. Time prevented observation of the recovery.

Seven experimental filters, each of 4 square feet area and 6 feet in depth, were erected at the city sewage disposal plant and charged with settled sewage. The filter media used were 1 to 3-inch granite, 3/4-inch, 1-inch, 1 1/2-inch, 2 1/4-inch

Raschig rings, a special ceramic block, referred to as Straight's block, and corn cobs. The waste was applied to the filters at a constant rate by means of a motor driven dosing mechanism.

This experimental plant was operated at three rates, about 3 months at each rate. During the first period, from August 16 to December 9, 1934, the dosage was 2 M.G.A.D. with a 6-minute dosing cycle, during the second period, from December 10, 1934, to April 1, 1935, 4 M.G.A.D. with a 3-minute dosing cycle, and during the third period, from April 2 to June 18, 1935, 8 M.G.A.D. with a 3-minute dosing cycle. The average B.O.D. concentration of the influent during each of the three periods was about 190 p.p.m.

The operation of the filters was followed by analyses of 24-hour composite samples automatically collected by a motor operated sampler.

During the first two operating periods the purification obtained on the smaller sizes of Raschig rings was materially greater than on the other media. Data are presented to show that the B.O.D. removal and nitrate production is a function of the surface of the medium.

During the third operating period the purification on all media was nearly the same. During this period the B.O.D. removal did not correlate with the surface of the medium. The nitrate production, however, was correlated with the surface of medium.

A study of the runoff characteristics of the various media was made with sewage before and after the microbial film developed, and with water before development of the microbial film. In connection with this work, the effect of surface tension on the runoff characteristics of a stoneware power packed with 3/4-inch Raschig rings was studied.

The 5 cubic yards of ceramic filter media used in this investigation were produced from Iowa clays in the Ceramic Engineering laboratories under the direction of Professor Paul Cox.

An estimate of the cost of producing ceramic media, together with opinions of ceramic manufactures is presented to indicate a probable cost under $5.00 per cubic yard.

A method of using the Duboscq colorimeter for nitrogen determinations is presented. By means of curves presented it is possible to use one standard nitrogen sample to cover a large range of concentrations of sample.

V. CONCLUSIONS

The conclusions arrived at as a result of this investigation may be conveniently considered under three heads: namely, characteristics of trickling filters, the feasibility of using ceramic filter media, and miscellaneous.

A. Conclusions Concerning Trickling Filters.

Evidence has been presented to show that:

1. Trickling filters have much greater capacity for purification than commonly thought. Under proper conditions rates of application of over 8 M.G.A.D. may be used.

2. The limiting factors for B.O.D. reduction and nitrification are not the same. That is, a high nitrate production may be obtained without a corresponding B.O.D. removal.

3. Ventilation is very essential for B.O.D. removal.

4. Nitrate production was correlated with the surface area of the filter medium.

5. B.O.D. removal was correlated with the surface area of the filter medium at low rates of application, but not at the 8 M.G.A.D. rate.

6. The microbial film greatly reduces the variation in runoff, and also greatly increases the contact time.

7. On the basis of variation in runoff, it is probable that even shorter dosing cycles may be advantageous.

8. Surface tension has a marked effect on the runoff characteristics.

An hypothesis has been presented to the effect that assuming adequate ventilation and reasonably short dosing cycles, the B.O.D. removal and nitrification are both functions of the surface area of the medium at any rate of application. That is, it is postulated that in the third operating period, the ventilation in the filters was insufficient to maintain the concentration of carbon dioxide in the filter atmosphere below the value inhibitory to B.O.D. removal, but that the oxygen content of this atmosphere was always greater than that inhibitory to nitrification.

B. The Feasibility of Using Ceramic Filter Media.

Evidence has been presented to show that:

1. Not considering the economics of the situation, ceramic products are very satisfactory as trickling filter media.

2. Ceramic products might possibly be able to compete with granite as a trickling filter medium. An estimate of cost of production is presented to show that ceramic filter medium can be produced for less than $5.00 per cubic yard.

3. The smaller sizes of Raschig rings produce unusually large amounts of nitrates, when treating a domestic sewage.

4. The smaller sizes of Raschig rings brought about a distinctly greater B.O.D. removal than granite at the customary rate of waste application (2 M.G.A.D.).

5. The volume of settlable solids in the effluent from

the filters containing the smaller sizes of Raschig rings was less than from granite.

6. Without the microbial film, the runoff from a ceramic medium was greater than would be expected from surface considerations as compared with granite.

7. 3/4-inch Raschig rings have runoff characteristics which have distinctly less variation than 1 to 3-inch granite.

8. With the microbial film developed, the runoff from a 6 foot bed of 3/4-inch Raschig rings dosed with sewage at the rate of 2 M.G.A.D. with a 6 minute cycle, was nearly constant.

C. Miscellaneous.

The investigation has led to conclusions on widely varying subjects, some of which are remote from the major objectives of this investigation.

1. Dried sheep manure was not found suitable for the continuous production of a synthetic waste having constant characteristics.

2. The use of the Duboscq colorimeter for nitrogen determinations is more rapid and more accurate than the standard method.

3. Well painted wood is quite satisfactory for the construction of experimental equipment in contact with sewage.

4. Moving metal parts in a damp location in an experimental plant should be either heavily galvanized or made of brass, aluminum or stailess steel.

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